# AMERICAN SOCIETY

OF

# CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

VOL. I.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## A.

## ADDRESS OF THE PRESIDENT,

JAMES P. KIRKWOOD.

DECEMBER 4, 1867.

It may be expected that on this, the first general meeting since the reorganization of the Society, I should have something to say of its past history and future hopes; but as regards the past, it seems needless to dwell on it further than as it may help us to reshape our course toward a more satisfactory future.

The origination of the Society is mainly due to the persevering efforts of Mr. Laurie, and the labors attending its conduct through the first stage of its existence fell mainly upon him and upon the Secretary, Mr. Morse. The Society gradually failed to interest the resident members from causes which may occur again and produce the same result. I will state the general causes as they appear to me, and whether you agree with me or not, I desire to lead your thoughts in this direction, that we may look our difficulties in the face and judge how we can avoid them or control them in the future.

During the first year of the Society's existence the want of funds obliged us to get along without rooms, and the routine meetings, as all of you remember, were held in Mr. Craven's office. When, however, the Society became possessed of funds, the same arrangement was continued, and for some years we were a Society without a habitation, with no rooms to which the country members could resort when in the city, and

to which both they and the city members could point as evidence of our being something more than a parchment Society. Prudential reasons kept us from venturing on that leap then. In this, the second stage of our existence, we have corrected that infirmity of our childhood, and if the Society is well sustained even by a moiety of the host of engineers scattered over this vast country, there can be little doubt of our being able to improve our present small beginnings as regards convenient rooms for our meetings and properties.

In another and more important point, as some will view it, we were deficient before, and this deficiency all of us were to blame for without exception, if I am not mistaken. I allude to the absence of professional communications from the members, one of which is wanted at every general meeting, to induce a fair attendance, to elicit discussion, and incidentally to provide a channel or bond of intercourse between us and the country members.

The non-resident members may many of them connect themselves with our Society from a kind of *esprit de corps*—a sort of free-masonry of good-will one towards the other, which prevails more generally with us, I think, than on the other side of the Atlantic; but this link of union between the Society and those distant members who can but rarely enjoy the privileges of its meetings, or the convenience of its rooms or library when it shall possess one—this link of good-will, I say, must be maintained and nourished by some palpable food. The short papers to which I have alluded on subjects of professional interest or a selection from them, must be printed, to admit of the doings of the Society here, reaching and interesting the non-resident members.

We cannot expect that an occasional letter from the Secretary in search of fees, or even in answer to some professional inquiry, will long be sufficient to induce those who cannot meet with us, to contribute the funds necessary to the successful existence of the Society. I speak more particularly of the non-resident members now, because without a very general and cordial support from them the Society cannot long maintain a respectable existence. There are a sufficient number of resident members to form a very pleasant club, but it will require at least two hundred members to meet the expenses necessary to establish this Society on a solid and respectable footing, and four-fifths of them would necessarily be non-resident members.

Now, we have a more numerous constituency, if I may so call it, of

engineers here than obtains either in England or France, and yet England has two flourishing engineer societies, and France has at least one. They possess the advantage of smaller territories, and greater nearness of all, therefore, to the central point. Here, because we are so widespread, so far apart from each other, and where, besides, we are not so frequently called to any metropolitan centers as are the professional men of England and France, we shall find it the more needful to create this other tie, and to maintain it by a regular distribution of so much of the proceedings of the general meetings as will be readable and valuable to the absent members.

It is not necessary that the preparation of such papers as I have alluded to should fall onerously on the resident members, because the outside members may be expected eventually to furnish the larger share of such communications, they being more numerous and having in reality more ample materials for that purpose and probably more leisure, but it becomes the resident members to take the initiative at this moment, and to give this working evidence of their earnestness in the present movement to revive the Society. There is no one of this last class who cannot contribute something to wake up our interest in each other's doings, and to draw forth those variations and apparent contradictions in practice, the knowledge of which enables us to make every step forward a nearer approach to that absolute correctness of perception and action so rarely reached except through the combined efforts of numerous minds plodding through long years of independent practice.

It is not necessary that the papers which we want should be very elaborate, involving much time and labor, but rather that they should be short and truthful, illustrating some point of professional difficulty or interest to which the individual's attention has been specially directed. Our failures in construction, where we are at liberty to mention them, will always be of more value to others than our successes ; but I say thus much of the character of such papers only to express my own feeling that a plain statement of any special point of engineering experience will always interest the Society and serve the purpose which such papers are intended to satisfy.

I will take the liberty of repeating that the dissemination of such papers, or abstracts of them, among the absent members is, in my opinion, essential to our continuous and successful existence. I hope that every city member will agree to prepare for us something of this

nature, and that steps will be taken to draw similar communications from such of the non-resident members as are in a position to furnish them. We shall then be able to have something before us at every meeting this winter, even if the general meetings should occur every fortnight, instead of monthly as at present.

In regard to the additional expenses in printing which my suggestion involves, it will be for the Society to say whether it is ready to undertake it, with such limitations as the circumstances may seem to require. I trust that I have said more than enough already to provoke your consideration of the points likely to secure to the Institution that usefulness and permanency which we all covet for it.

## NOTE FROM THE COMMITTEE

ON

# PAPERS AND PRINTING.

The accompanying short address, read at the monthly meeting of the 4th December last, although confined to a matter of business, has been ordered to be printed and distributed to the members.

A perusal of the paper will sufficiently explain its object, which was, in brief, to urge upon members the necessity of rendering the meetings of the Society attractive, by the preparation of professional papers, to be read and discussed at these meetings.

If it is desirable to have a Society which shall represent the profession, and further that kind of intercommunication which can in no other way be so readily secured, it is incumbent on the members to render it that kind of active countenance and support without which it will soon cease to possess any influence, and will become worthless as regards any benefit derivable from a connection with it.

The support alluded to includes especially contributions to its fund of information, in the form of communications on professional subjects. It has also in view donations of maps and reports, especially when these last are accompanied by some manuscript explanation or summary of the matter of the reports, whereby their drift can be brought shortly or distinctly before the Society at its regular meetings.

A little reflection will satisfy every one that a cheerful effort on the part of each member to throw in the mite of information within his reach will give life to our proceedings, and render our success certain.

At the meeting of the 4th December, a committee consisting of Gen. George S. Greene, Col. J. W. Adams, and the Secretary, Mr. J. O.

Morse, was appointed to have in charge the soliciting of such communications, and to arrange for the reading of them when the writer could not be present. This committee will be glad to hear from you at your convenience, through any of its members, and will arrange to bring before the Society any matters which you may prepare, should you not be able to be present yourself. It begs that you will freely communicate your views as to any particular matters of practice within your experience, which it will endeavor to meet either as regards time or otherwise.

GEORGE S. GREENE,

*Chairman.*

Secretary's Rooms, 12 Chamber of Commerce Buildings, corner of William and Cedar Streets.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## I.

## DESCRIPTION OF A LINE OF LARGE WATER-MAINS, LAID BY THE CROTON AQUEDUCT DEPARTMENT OF THE CITY OF NEW YORK; AND AN INQUIRY INTO THE CAUSES OF FAILURE OF A FEW OF THEM.

At a regular meeting of the Society, held on the 29th of January, 1868, the following paper was read by A. W. Craven, Civil Engineer:

The failure or breaking of some *large* cast-iron pipes on the Croton Aqueduct, during the past season, was so unexpected at the time, and has given rise to so much subsequent speculation, that I have thought that a precise narrative of all the facts thus far ascertained might not be uninteresting to the society, and might, by leading to further discussion, result in a satisfactory determination of the cause of the failure.

The pipes were of unusual size, and the care taken in filling them was thought to be all-sufficient; and, if this failure of a portion of them should lead to a better knowledge of the required construction and proportions of the castings themselves and of the manner of laying them, the present misfortune will be of great ultimate value. It is a fact, in engineering, of very considerable importance, and I lay the details before you, not without misgivings as to their clearness, but still with the hope that they may result in some professional benefit to us all.

By an Act of the Legislature, the Croton Aqueduct Board has recently been obliged to change the line of the Aqueduct from near the point of

its intersection with Ninetieth street to within a short distance of the influent gate-house of the old Receiving Reservoir.

The change of the location made necessary an alteration, also, in the grade and character of the conduit. The portion of the Aqueduct thus discontinued was, like the rest of the line, built of masonry, and maintained also the gently descending grade common to the whole line, so that at no point was there any upward pressure on the arch.

By the change of the location, however, the Aqueduct was made to conform to the lines and grade-surfaces of Ninetieth street and Eighth avenue; the new Aqueduct would, therefore, be below the surface of these streets, and be throughout its whole length lower than at the two ends where it was connected with the old line, being, in fact, an inverted syphon.

The extreme vertical depression between these ends was 14.54 feet, and the general depression about 13 feet; and it was determined that, under the circumstances, economy and safety called for the laying down of cast-iron pipes, instead of constructing the new work in masonry.

Two lines of pipes were laid. Their interior diameter is 6 feet; their thickness 1 inch and $\frac{3}{8}$. On the tangents these pipes are in lengths of 12 feet. On the curves, at the intersection of the line with Ninetieth street (which was a curve of 76 feet radius), and that at the corner of Ninetieth street and Eighth avenue (radius 85 feet), the pipes are in lengths of 6 feet. On the curve from the Eighth avenue into the Central Park to where the pipes strike the old Aqueduct again, the radius is 200 feet, and the lengths are each 9 feet. The pipes on all of these curves were straight, but to enable us to lay them more accurately in the line of the curves, and to make more perfect joints, the spigot ends were bevelled, and the interior of the hubs were made sufficiently elliptical to correspond with the ends as thus bevelled.

The bed on which these pipes were laid was varied, comprising rock excavation, earth excavation, and embankment.

The accompanying drawings will show the position of these differing foundations.

Under each pipe were two blocks of wood, one near the hub and the other near the spigot end, with two wedges on each block, to bring the pipe to a uniform bearing.

In the process of covering the pipes care was taken, as usual, to have the earth well rammed under and around the sides below the centre, and

the rest of the filling compacted in the ordinary manner. This covering being partially completed, the water was let into the pipes; and to furnish those unacquainted with the locality with all the data necessary to the question involved, it seems proper to describe here the exact condition of the portion of the aqueduct, including the new work in pipes, which was then filled.

At a distance of 500 feet from the commencement of the pipes near Ninetieth street, there is a gate-house called the Junction Gate-House, built on the line of the old conduit, and from which the water is now let into the old conduit, and also into a branch aqueduct leading to the New Reservoir, each conduit being controlled by separate gates.

From the lower end of the pipes, where they again join the old conduit in the Central Park, to the influent gate-house of the Old Reservoir, the distance is 655 feet.

Both of these portions of the old conduit, were, of course, empty during the time of laying the pipes, and at the time now spoken of—the Old Reservoir being meanwhile kept full by a pipe connection from the New Reservoir. The length of each line of pipes is about 2 560 feet, and the total distance between the gate-houses spoken of is, consequently, 3 815 feet. In letting in the water, previous experience had taught us that great care was necessary to guard against the effects of the ram, or concussion, so liable to take place in filling inverted syphons; and, it was thought that the requisite care *was* exercised in this case. Only one of the gates at the Junction Gate-House was used, and was raised but 9 inches. As the gate raised was three feet wide, the sectional area of the opening was but 324 inches, or $2\frac{1}{4}$ square feet; while the area of the conduit of masonry is $53\frac{1}{3}$ feet, and the combined area of the two pipes $56\frac{1}{2}$ feet.

The water in the Junction Gate-House, behind the gates, stood at the time 8 feet 8 inches above the bottom of the gate; giving an effective head of 8 feet $3\frac{1}{4}$ inches.

Of the time taken to completely fill the pipes and old aqueduct, no precise note was taken, but it was about 3 hours.

When the whole was filled to the level of the water in the Junction Gate-House, but before the influent gates of the Old Reservoir were opened, the gate at the junction was shut down.

In passing over the line about $\frac{3}{4}$ of an hour afterward, it was discovered that some of the pipes had given way.

The water was immediately drawn off, and on examination it was found that out of 480 pipes, the whole number in both lines, 19 had been cracked.

Excepting two, one of which was 3 feet 8¾ inches and the other 8 feet 9 inches in length, these cracks ranged in length from 2 inches to 2 feet 9½ inches, and in width from a merely perceptible line to about ⅛ of an inch. They were invariably in or very near the centre of the bottom of the pipe and continued in the centre quite closely for their whole length. Excepting one which was at the spigot, all of the cracks occurred at the hub ends.

The question is, What caused this failure? It will be seen by the accompanying plans that the character of the foundation is not to be considered, as the breaks occurred when the pipes were laid upon embankment as well as when laid on rock. The profile here shown is that of the interior bottom of the pipes ascertained by a line of levels run immediately after the water was drawn off. It will be seen by this profile that there was at no point where failure occurred any perceptible vertical deflection, and certainly not sufficient to have strained the pipes at the joints.

Was it the superincumbent weight? Examinations and some experiments were made touching this theory.

By an accurately graduated gauge, measurements were taken of the interior vertical and horizontal diameters of every fourth pipe on each line—both of these measurements taken at the same point, and the differences noted. In such of the pipes as were broken, these measurements were taken twice; the first series while the embankment still rested on them, and the second after the pipes were uncovered, and thus freed from any load.

By the note-book it will be seen that, exclusive of the pipe which was cracked for nearly its whole length, the maximum difference between the vertical and horizontal diameters of the 18 pipes broken, taken when covered and at the hub ends, was 1.67 inches; the minimum $\frac{7}{100}$ of an inch, and the average $\frac{58}{100}$ inch; elongation of horizontal diameter was therefore $\frac{58}{100} \div 2 = \frac{29}{100}$ of an inch.

Of the 461 pipes not broken, the maximum difference was $1\frac{37}{100}$ inches, the minimum nothing, and the average $\frac{63}{100}$; elongation of horizontal diameter was consequently $\frac{31}{100}$ inches.

The experiments bearing on the question of superincumbent weight were made as follows:

*First.*—Two lengths of new pipe, merely laid upon the open ground uncovered and unconnected, were measured, to ascertain the elongation of the horizontal diameter, caused by their own weight alone. In each pipe measurements were first made of the horizontal and vertical diameters, both at the spigot and hub end. Each pipe was then rolled over 90 degrees of its circumference, so that what was before the vertical was now the horizontal diameter. The greatest difference in the hub ends shown was $\frac{8}{100}$ of an inch, and in the spigot end $\frac{12}{100}$ of an inch.

You will see by the notes that the differences in the diameters of pipe No. 23 (broken), while covered, was at the hub only $\frac{7}{100}$ of an inch, and at the spigot it was $\frac{21}{100}$.

Three joints of pipe were then put together, supported on blocks, the joints caulked, the earth rammed under and around them, and the covering filled in above them; in all these particulars the work being similar to that in laying the lines of pipes in question, but the covering, or load, was carried to a much greater extent.

The centre pipe (12 feet long) was loaded in the manner shown in the accompanying diagram. The calculated weight upon it was 7.36 tons per linear foot for its entire length. This pipe being measured before being loaded, the difference between its horizontal and vertical diameters was $\frac{115}{1000}$ of an inch; when loaded, the difference was $\frac{75}{100}$ ($\frac{3}{4}$) of an inch, or an elongation of the horizontal diameter of $\frac{3}{8}$ of an inch.

The greatest load upon any broken pipe, calculating both the filling and the weight of the water, was but 4.05 tons per linear foot, the excess of load in the experiment was therefore 3.31 tons or nearly double.

Moreover the tendency of excessive superincumbent weight would (excepting in very peculiar situations) be to break the pipe at or near its horizontal diameter, which, taken in connection with the results of the experiments and examinations made, would seem to show that this theory is not sustained by anything yet developed.

It should not, however, escape observation and thought, that the conditions of the pipe under the experiment just described and those broken in the line of the work may have been different in regard to the load. In both cases it was intended that the earth should be rammed under and around the lower half of the pipes so as to ensure an uniform bearing for their entire length, and thus prevent any pipe from resting its whole weight solely on two points, viz.: the blocks at each end. It

might be, however, that this was well done under the pipes experimented upon and imperfectly done under those broken in the line.

In the absence of positive proof, I have assumed that the Inspectors tried to do their duty in this particular, and that in most cases the pipes were properly supported by ramming.

Should it have been, however, that the pipes in the experiment were perfectly supported and the others not, the weight on the blocks at the hubs (the point where the failure occurred) would be for the 9 feet pipes $18\frac{2}{10}$ tons, and in the 6 feet pipes $12\frac{1}{10}$ tons on each point of support, the blocks being 4 feet apart, 2 feet on each side of the hub.

Was it owing to previous straining of the hubs from excessively hard caulking?

In our experience, pipes have been broken under the strain of the caulking, but it occurs so seldom that it seems unreasonable to assume that in this case so many as 19 instances should be afforded. Experiment was made on this point, but in the pipe tested it was found impossible to break the hub by the use of any caulking hammer in our possession.

After the lead joint was set up as firmly as it was possible to drive it, iron wedges were driven into the joints with heavy hammers, but without breaking the pipe.

Of course there is great difference in strength of iron pipes, even when made of the same metal, arising from imperfections in the casting, difference in the shrinkage while cooling, &c. But the strain put upon the hub tested was so far in excess of that in the ordinary caulking of pipes as to seriously impair the soundness of this theory. Besides, one was broken in the spigot end, where the caulking would operate to strengthen rather than to strain the pipe too near the breaking point.

Was the failure owing to the weight of water in the pipes acting directly upon the curves in the lines which were upon a descending grade, and tending to move the pipes bodily out of their original place? One answer to this may be found in the fact that the pipes on the curves or immediately next them would be the only ones affected by this force, whereas the cracks were not confined to the curves, but occurred on the tangents, and even at points the most removed from the curves.

Again, this force would act more powerfully as the radius of the curve diminished.

Out of the 19 pipes broken, 9 were on the lower curve near the Old Reservoir, a curve of 200 feet radius, and a distance of 314 feet, while on

the upper curve at Ninetieth street, 76 feet radius, and an arc of 119.38 feet, but one break occurred, and on the central curve, Ninetieth street and Eighth avenue, the radius being 85 feet, and the arc 133.52, feet no break whatever occurred. 9 of the breaks occurred on the tangents.

Moreover, it seems hardly possible that the weight of water was sufficient to move out of place so immense a load as was represented by these pipes filled with water and covered with compacted earth.

Was the failure caused by the ram or hammer of the water when its flow was suddenly checked ?

The precise power of what is called a ram in water-pipes, can very seldom be determined, because in all cases it is extremely difficult, and in most cases absolutely impossible, to determine the velocity of the water at the moment its flow is checked. We know from experience that it has often proved sufficient to break the pipes, but how much greater than the necessary force existed at the time is seldom ascertained. The want of precision in data, therefore, makes this question one always difficult to investigate, and in the case before us, the difficulties are by no means less than usual ; but I think there are one or two facts which were noted at the time and which help us in discussing the question whether the failure of these pipes is to be ascribed to the ram.

It has been shown that the distance between the two gate-houses, or the length of pipe and conduit filled, was 3 715 feet.

To fill this space it took 206 534 cubic feet of water. The time taken in filling is assumed to be three hours.

The average velocity, therefore, of the flow of water through the gate, into the conduit and pipes, must have been 8½ feet per second.

It has been ascertained very positively that when the water was shut off, or the gate was closed at the Junction Gate-House, the water rose in the influent gate-house, Old Reservoir (from which there was no effluent gate open at the time), a height of nine inches above the point to which it would be in a state of perfect rest.

The space in which the water is visible in this Gate-House is a chamber or back-bay about 10 feet square. The whole surface of water in this chamber was observed to rise uniformly and quietly, and without any very marked superficial disturbance, to the height stated, and then subside with equal uniformity below the point of rest. This rise and fall was repeated several times. No note was taken of the time occupied in each pulsation, but the motion was distinctly visible both when the water

was rising and when receding. It could, therefore, not have been more than a few minutes in any one case, and, from what I could ascertain from the witness, the first rise and fall did not occupy many seconds.

Here, then, seems to be positive evidence of a recession or reflux of the whole body of water following immediately upon shutting off the inlet at the upper gate-house.

To what distance, and with what comparative force or velocity this reflux was carried, we have no means of judging.

To what extent there was any disturbance from this cause in the upper or Junction Gate-House, we do not know, for the superintendent left that building within a few minutes after the water was shut off, without noting any disturbance in the surface at that point, but that the vast body of water in the pipes was in motion at the lower end, and that this motion must have been transmitted, to a greater or less degree, throughout the whole length of the pipes, seems certain. The distance from the south Gate-House, the point at which the flow of the column of water was checked, to the lower or nearest end of the pipes or syphon, was 655 feet; the distance from this point to the nearest pipe broken was 117 feet.

The bottom of this pipe was 4.78 below the bottom of that part of the aqueduct just spoken of. The weight of the water which, at the time of its recession, was in this length of conduit and pipe combined, was 1 070 tons.

It would require but very slight velocity, with such a weight, to bring a very great strain upon the whole length of the pipes.

If there was any ram at all (as there is good reason to suppose), it must have been sufficient, with other causes which I will speak of presently, to have produced the failure.

The fact that of the 19 pipes broken, 9 were within a space of 250 feet of each other at the lower end of the line, where the shock of this ram would have been first felt and partially expended, would go to strengthen the theory that it was to this cause the failure was due.

The bottom of the furthest one of these pipes was 12 feet below the grade of the aqueduct at its junction with the pipes, and as the interior height of the aqueduct is 2 feet 5 inches greater than that of the pipes, the head upon the latter at this point was 14 feet 5 inches.

The other causes to which I alluded as aiding to break the pipes I have not connected specially with any of the theories suggested, because they may have been common to all.

It is the possibility that the pipes broken had been strained too near the breaking point by shrinking at the time of casting, and that this strain had been further increased by the caulking.

From the shrinkage alone the pipes might have been in such a condition as to be unable to bear any further strain, and, perhaps, in the two combined may be found a solution of the question involved, quite as probable as any other which has been suggested.

Whatever be the real cause of this failure, I am convinced that if large pipes must in any case be used, an alteration should be made in their shape and dimensions.

If again obliged to use pipes of this calibre under similar circumstances, I would increase the thickness to two inches. This would diminish the chance of injury during the cooling of the metal. I think, also, that in pipes of very large size, additional security would be ensured by dispensing with the hub or bell ends, and using sleeves as the means of making the joints.

I present herewith drawings of the hub of the pipes as cast, and of sleeves used in the repairs.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## II.

## BLASTING WITH NITRO-GLYCERINE.

A Paper read before the Society 4th March, 1868, by Edward P. North, Civil Engineer.

I have been led to introduce to your notice the subject of this paper (Nitro-Glycerine, or Nobel's Blasting Oil), because its application to blasting is comparatively new, and consequently, not generally known. As over three-fourths of a ton has been used on the New Canaan Railroad, of which I am now in charge, I may, perhaps, be able to convey some ideas of information and interest. I have, however, to regret that no accurate accounts of the comparative cost of quarrying with powder and nitro-glycerine have been kept on this road, and that I can only give impressions as to the cost. It may be as well here to give a little sketch of nitro-glycerine, and to compare it with powder and gun-cotton.

Gunpowder is composed of a variable quantity of nitrate of potassa, sulphur, and carbon (charcoal), the nitrate of potassa being replaced in cheap powder by nitrate of soda. Some Prussian sporting powder analysed by Prof. Bunsen, of Heidelberg, contained :

| | | |
|---|---|---|
| Nitrate of potassa | $KO, NO^5$ | 78.99 |
| Sulphur | S | 9.84 |
| Carbon | C | 7.69 |
| Hydrogen | H | 0.41 |
| Oxygen | O | 3.07 |
| | | 100.00 |
| On burning it, he found remaining as residue | | 68.06 |
| And the gas amounted to | | 31.38 |
| | | 99.44 |

The residue consisted of :

| | | |
|---|---|---|
| Sulphate of potassa | KO, $SO^3$ | 42.27 |
| Carbonate " | KO, $CO^2$ | 12.64 |
| Hyposulphite " | KO, $S_2$, $O_2$ | 3.27 |
| Sulphide of potassium | KS | 2.13 |
| Sulpho-cyanide of potassa | K Cy, $S_2$ | 0.30 |
| Nitrate " " | KO, $NO^5$ | 3.72 |
| Sulphur | S | 0.14 |
| Carbon | C | 0.73 |
| Carbonate of ammonia | $NH^4$, O, $CO^2$ | 2.86 |
| Residue | | 68.06 |

The gas consisted of :

| | | |
|---|---|---|
| Nitrogen | N | 9.98 |
| Carbonic acid | $CO^2$ | 20.12 |
| Carbonic oxide | CO | 0.94 |
| Hydrogen | H | 0.02 |
| Hydro-sulphuric acid | H, S | 0.18 |
| Oxygen | O | 0.14 |
| | | 31.38 |

Gun-cotton was discovered by Prof. Schonbein, about 1846, and its manufacture was almost immediately commenced, but never with financial success till lately. It is now being made in England by Prof. Abel and Messrs. Thomas Prentice & Sons, a very interesting account of whose process can be found in the last volume of " Engineering," pages 408, 431, and 467.

Nitro-glycerine was discovered in 1846, by Sobrero, but nothing was done with it till 1863, when Alfred Nobel patented its application to blasting. Gun-cotton and nitro-glycerine are made, the one from cotton and the other from glycerine, treated with nitric and sulphuric acid, the action of the sulphuric acid being, in each case, to intensify the action of the nitric. In the case of gun-cotton, cotton which has a formula of $C_{12}$, $H_{10}$, $O_{10}$, is dipped into a mixture of three parts of sulphuric acid and one of nitric acid, by weight. Some of the oxygen in nitric acid goes to the hydrogen, forming water, and the formula stands $C_{12}$, $H_7$, 3 ($NO_4$), $O_{10}$+6HO, three parts of the hydrogen in the cotton being replaced by three parts of nitrous acid. On its explosion, it is all resolved into gases, namely :

| | | By volume. | By weight. |
|---|---|---|---|
| Carbonic oxide | $CO$ | 28.95 | 29.97 |
| " acid | $CO^2$ | 20.82 | 33.86 |
| Light carburetted hydrogen | $C^2, H^4$ | 7.24 | 4.28 |
| Hydrogen | $H$ | 3.16 | 0.24 |
| Nitrogen | $N$ | 12.67 | 13.16 |
| Carbon | $C$ | 1.82 | 1.62 |
| Steam | $HO$ | 25.34 | 16.87 |
| | | 100.00 | 100.00 |

Leaving no residue. As to its relative strength, the article in "Engineering" already referred to says it is ten times stronger than powder. According to Von Leuk, in blasting, one pound of gun-cotton is equal to 6.274 pounds of powder. According to a commission appointed by the French government, the explosive power of gun-cotton depends, in a measure, on the degree of compression, and, in the mean, is about three times that of gunpowder. When uncompressed, it will burn more freely than gunpowder, but by compression its rate of burning can be brought below that of gunpowder.

Gun-cotton, according to Prof. Abel, when well made, can be kept for a long time without undergoing change, and can be transported as safely as powder; but when impure and acid, a gradual decomposition takes place, the result of which is an explosion.

Nitro-glycerine is made by treating glycerine, which has the formula $C_6, H_5, N_3, O_{18}$, with nitric and sulphuric acids, as in the case of cotton, and the chemical reactions are nearly the same, it being in both a case of the substitution of nitrous acid for a part of the hydrogen. By explosion, according to an article in the London Mechanics' Magazine, September, 1857, one volume of oil is converted into 429 volumes of carbonic acid, 554 volumes of steam, 39 volumes of oxygen, and 236 volumes of nitrogen—1,298 volumes in all, for one volume of liquid oil, being thus theoretically, five times more effective than its bulk in gunpowder; but by the greater amount of heat generated by the explosion, and the consequent higher tension of the gases, it is really thirteen times more effective by bulk, and eight times by weight, than the same. The United States Blasting Oil Company, in a pamphlet published by them, assert that nitro-glycerine has thirteen times the strength of powder by volume, and ten times by weight. It is a lightish, yellow, oily liquid, with a specific gravity of 1.6, nearly insoluble in water, not volatile,

taking fire at 360° F., and freezing at from 40° to 36° F. When impure and acid, it decomposes spontaneously, with an escape of gas and the formation of oxalic, $C_4$, $O_6$, 2HO, and glyceric, $C_6$, $H_6$, $O_8$, acids. Under these circumstances it is liable to explode.

My attention was first called to the use of nitro-glycerine by the fact that our contractor, Lawrence W. Myers, was losing money, on account of the extreme hardness of the rock in one cut, and its wetness in another. As I advised the use of nitro-glycerine, I, of course, took a great deal of interest in its success, loading and firing a great many of the holes myself. I will give a sketch of the circumstances and results as they appeared. In one cut, which in its deepest part was about 12 feet, the rock was mostly feldspar and mica, in large crystals ; but it was very wet, springs forcing themselves up through the bore-holes, so that they could not be puddled. Here the fact that nitro-glycerine was entirely unaffected by water rendered it particularly valuable. The mode of procedure was this : A single hole was put down to grade about the centre of the cut, a foot or two further back from the face than the depth of the cutting, so as to have the line of least resistance a vertical one ; from five to eight pounds of nitro-glycerine were poured in. A tin cartridge about four inches long, and three-fourths in diameter, filled with powder, into which a waterproof fuse was introduced, was put into the nitro-glycerine, and the hole filled with water. These charges were very effective, in some instances loosening over 100 cubic yards, so that it could be readily barred out, while that immediately around the charge was burned to a soft white powder. The quarymen said it had turned to lime. About 50 per cent. of the rock was usually so fine as to be readily thrown into carts without sledging or block-holing, while that furthest from the charge was in masses of two or three cubic yards.

In the other cut, which for about 50 feet was 21 feet deep, and contained about 8,000 cubic yards, the rock was very hard feldspar and quartz, so that sometimes drills were used up faster than one to an inch. In this cut it was found better to have the line of least resistance a horizontal one. There was no grain to this rock, it not splitting or breaking more readily in one direction than another. This cut was worked from both ends, one foreman using small holes, and, of course, more of them, while the other sank his holes in the centre, nearly to grade, and tried to throw out the cut at one shot. Though the plan of single holes was not always successful, still, on the side on which it was tried, there was

an economy of about 10 per cent. in labor per yard moved, and a slight loss in the quantity of rock per month, which latter item I think due to the fact that too much was put before the single holes, as the rock in the face of the cut was sometimes in masses of 5 or 6 cubic yards, requiring block-holing.

As this cut was perfectly dry, and water had to be brought from some distance, water-tamping was dispensed with. The same cartridges were at first used as in the wet cut, only the fuse was cut off short, and they were dropped into the hole after being lighted. This was found objectionable, as there being nothing to confine the gases generated by the explosion of the powder, they would sometimes fail to produce either heat or concussion enough to explode the nitro-glycerine, though they would ignite it and cause it to boil and smoke till sometimes, after about ten minutes, the glycerine would either go out or go off, which produced a delay, as the men did not like to go and drop in another cartridge. A large copper cap, known as Nobel's patent cap, that fitted closely over the end of the fuse, and contained percussion powder, was also used, but failed for lack of power or heat. The plan finally adopted was to pour in the glycerine, and then put down a light wad of hay or dry grass, on which some powder was poured, with which the fuse was connected. The hole was then filled with loose sand and fired. After having seen many holes fired with and without tamping, I doubt if tamping is of much more use than to ensure the explosion of the glycerine.

The United States Blasting Oil Company, in the pamphlet already referred to, recite as one of the advantages accruing from the use of nitro-glycerine, that smaller holes can be used, which, I think, is poor economy, unless it be in exceptional cases; that it is better to have the hole large, so that the charge of glycerine can be in as compact a position as possible.

The effect of nitro-glycerine differs from that of powder in consequence, I suppose, of its greater force and quickness of explosion, in that, that powder, when fired, where the line of least resistance is a vertical one (the bore also being vertical, and the rock homogeneous), will form a tolerably uniform crater, with the sides sloping according to the hardness of the rock. When the line of least resistance is a horizontal one, and not too long, the rock being solid, the rock will throw out what is before it, leaving the back uncracked, and no sign of action below the bottom of the hole.

Nitro-glycerine, on the contrary, in the first case, will form a well, and if the rock is not too hard, the bottom diameter will be greater than the top. Nor, as far as I have seen, will the action ever be concentrated on the line of least resistance, but will extend back from the hole and downward to a greater or less distance, according to the hardness of the rock. I think that this action of nitro-glycerine, in connection with the fact that its explosive force is uninfluenced by the presence of water, will tend to its being the only explosive agent used in all subaqueous operations; for with any depth of water, it will be unnecessary to drill holes, only to sink a flask of nitro-glycerine on to the rock and fire it.

The harder or wetter rock is, the greater will be the profit of nitro-glycerine over powder, and though I think the old-fashioned way of squibbing holes, and then using heavy charges of slow-burning powder, is the best for blasting hard-pan or partially indurated clays, I think for slate, or anything harder than that, there will always be a saving of money in the use of nitro-glycerine, besides a great saving of time.

Mr. Meyers, our contractor, who has had a great deal of experience in blasting operations, says that in hard, dry ledges, he thinks full double speed could be made with glycerine than with powder, and in wet ledges fully four times the speed with the same force of men; for besides a less number of holes being required, there is no necessity for puddling the holes or water-proofing the blasting charge of powder, and a hole can be loaded and fired in much less time with nitro-glycerine than with powder; and as a matter of economy, he would prefer to pay $1 12½ per pound for nitro-glycerine, to having powder given to him for hard, dry ledges, or to having $10 per keg given to him for all the powder he would use in blasting wet ledges. He also thinks nitro-glycerine much safer than powder. From the fact that nitro-glycerine explodes with so much violence that it would burst any cannon, its strength cannot be ascertained as that of powder can, and I think it will be difficult to arrive at any exact measure of its strength. I can, however, give one or two examples. I once put a little over a pound of glycerine in a hole (in the hard ledge above mentioned), two inches in diameter, that was 18½ feet deep, and 22 feet from the face of the cut at the bottom of the hole. This charge was fired without any tamping over it. It made a crack about 8 inches long on the surface, that ran down the hole as far as I could see, and cracks were made in the face of the rock so that smoke was blown out of them. I afterward put 23 pounds

of glycerine, as nearly as I could measure, in the same hole, poured in some powder, and filled the hole with dry sand. 210 cubic yards of rock were loosened, so that it was mostly barred out, though some masses required block-holing, but the quantity mentioned was removed without any large blast, and the back of the cut was left well shattered for the next blast. If nitro-glycerine is used in the city, the blasts should be well covered, for a house standing about 1 200 feet from the cut, and on somewhat higher ground, had a stone come through the roof, apparently falling vertically ; and the men always went about 400 feet from the blast, and often had to dodge at that.

In regard to the relative safety of gunpowder, gun-cotton, and nitro-glycerine, I think the last named is the safest agent. I do not wish to be understood to underrate the disastrous effects that would, probably, and have occurred from an accidental explosion ; only to say that I think, with properly made, unfrozen nitro-glycerine, the cans packed in plaster of Paris, as the law requires, it is safer than powder. I speak of its being unfrozen, because during the use of it on this road, from last September until the middle of January, the only instance in which any glycerine was exploded without the aid of powder was a small frozen piece that was crushed between two stones. Nitro-glycerine was placed in the hands of six different foremen, and by them in the hands of the men; was carried unprotected in sixty-pound cans up and down the line, frozen and unfrozen, in dump-carts ; and was generally treated with the recklessness with which Irishmen treat powder. And as blasting material is usually used on roads, it must be the safest of the three ; for as there is no necessity of any tamping but water-tamping, if a charge miss fire, there is no solid tamping to cut out—at the danger of the driller's life—as with powder. For if water has been used, another cartridge can be dropped in in a minute ; or if sand has been used, a portion of it can be scraped out, and a small charge of glycerine poured in and fired on top of the old charge. Besides which, gun-cotton will ignite and explode not only from a light spark, but from a flame, thus making it the most dangerous of the three ; while powder, though it cannot be ignited without the aid of a spark, or something red-hot, can be ignited by any spark, such as one flying from drills or from rocks falling ; and nitro-glycerine cannot be exploded, even if ignited, unless confined, and in that case a spark could hardly reach it.

I will now read from the pamphlet already referred to :

*Experiments made at Stockholm, 28th September*, 1865.

*First Trial.*—A quantity of nitro-glycerine was poured on a flattened stone ; a red-hot iron bar was then made to wear along the surface of the nitro-glycerine without igniting it, and finally placed into the blasting oil, spread on the stone, which, after being warmed, partly took fire, and burned with a flame, but without exploding. After removing the iron bar, some undecomposed oil remained on the stone.

*Second Trial.*—A cavity in a stone was filled with nitro-glycerine ; a burning wood shaving was introduced, and on stirring it, the nitro-glycerine burned with a flame, but without exploding. The combustion ceased as soon as the shaving was consumed.

*Third Trial.*—Several glass bottles were filled with nitro-glycerine ; these bottles were thrown with great force from a height against a rock below. The bottles were shattered, but without, however, exploding the oil.

*Fourth Trial.*—On the suggestion of some of the gentlemen present, who desired that the preceding trial should be repeated with the nitro-glycerine warmed to more than ordinary temperature, three bottles filled with this agent were heated in warm water to 50 deg. Celsius, or 120 deg. Fahrenheit. These bottles, thrown with great force against the rocks, shattered likewise, without causing an explosion of the blasting oil.

*Fifth Trial.*—A cartridge of tinned iron, filled with nitro-glycerine, was placed in a kettle with boiling water, without producing any result.

*Sixth Trial.*—Two flasks of tinned iron (of the same kind as those used by the Nitro-Glycerine Company), filled with nitro-glycerine, were packed into a wooden box, as is customary in forwarding them. After having screwed down the cover, this box was thrown from a height of nine or ten feet, upon the rock below, and without any result.

You will have noticed that we found difficulty in exploding the glycerine, and I think that all of Nobel's patent lies in the application of sufficient heat or concussion to effect the explosion.

In regard to the accidents that have occurred : the one in New York almost surely occurred from the nitro-glycerine having leaked into the sawdust in which it was packed, and oxidation and combustion followed,

as surely as if oil had been put on the same sawdust, and it put in a warm place, only the combustion was rather more rapid. I have been informed that the accident at the express office in San Francisco occured from the same cause. As there is now a law against transporting nitro-glycerine in glass, or in any mode except tin cans, packed with plaster of Paris in wooden boxes, we will probably have no more such accidents.

At Aspinwall, a case of nitro-glycerine was dropped into the hold of the steamship; few of us would have cared to have been on the deck when a barrel of gunpowder was treated in the same way. At Bergen, red-hot iron was brought in contact with tin and solder that melts at from 360° to 475° F., and nitro-glycerine would be of little use as a blasting material if it had not proved disastrous. At the risk of reiteration, I will sum up the advantages possessed by nitro-glycerine over gunpowder and gun-cotton.

1*st*. That, being of greater strength, there is a great saving in drillers' wages, as fewer holes have to be made, and the charge of glycerine can be put into the rock much more compactly. For instance, if, to break up a certain rock, 1 foot of depth in the bore-hole was required with glycerine, 13 feet would be required with powder, which would necessitate 6 feet of additional drilling if but one hole was used; but 13 feet of powder could not be exploded in a 2 inch or 2¼ inch hole so that it would be effective, on account of the slowness with which it burns, so that additional holes would have to be drilled, with in each an allowance of at least ⅓ of the depth for tamping. With gun-cotton there would not be so much difference.

2*d*. That nitro-glycerine is not injured, either permanently or temporarily, by water or moisture, which enables us to use water-tamping, a great saving of time and risk of life, impossible with either of the others; and it can be stored in damp cellars, or under water, without the necessity of drying it before using, as in the case of gun cotton, or having it ruined, as with gunpowder.

And lastly, the difficulty of exploding it renders it the least dangerous to human life.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

# TRANSACTIONS.

## III.

## CORROSION OF IRON.

At a regular meeting of the Society, held on the 29th January, 1868, the following paper was read by Wm. J. McAlpine, Civil Engineer :

Formerly it was assumed that iron was subject to rapid corrosion when immersed in water, or exposed to the alternations of the water and the atmosphere, and the every-day experience of constructors seemed to confirm this opinion. Wrought-iron bolts in wooden dams and similar places and in works wholly under water, frequently rapidly oxidize. Cast-iron water-pipes in city streets are frequently found greatly corroded ; and cannon and shot immersed in sea-water for half a century, and sometimes less, have been found with a mass of the metal entirely changed from iron into plumbago, or deeply pitted by oxidation.

During the earlier discussions of the subject, the inquirer was frequently staggered in his belief in the generally received opinions, by finding both wrought and cast-iron which had been immersed many years, but slightly oxidated, and wholly unchanged in its structure.

The cannon of the "Royal George," which had been submerged half a century, when first taken out were so soft that the metal could be cut with a knife, but immediately hardened on exposure to the air, and were again fired. Some muskets and cannon, sunk in Lakes Erie and Ontario

during the war of 1812, were, forty years afterwards, found to be but slightly rusted.

An iron steamer, the "Aaron Manby," which was launched in 1822, and kept in constant use for twenty years, was carefully examined, and no signs of corrosion found; and, ten years later, it is stated that she had required but small repairs for the whole period.

William Fairbairn also cites many cases where iron ships, which had been ten to fifteen years in salt water, showed no corrosion.

This subject was much discussed in England, in 1850, and the unexpected absence of corrosion in wrought iron ships, even on the interior surfaces and iron parts, was then attributed to the vibration of the metal, as was noticed on comparing the amount of the corrosion of railway bars in the track with those laid outside of it.

Plumbago was obtained from cast-iron immersed in acidulated water in 1822, and forty years later Dr. Calvert produced the same result by placing it in sea and foul water.

A dozen years earlier, Mr. Mallett reported his well-known experiments on the corrosion of different kinds of iron in pure and foul atmospheres, and in clear, foul, acidulated, and salt waters, and arrived at the following general conclusions:

That iron exposed to water holding air in combination corrodes on the surface either uniformly or in places, by rust or by the conversion of the iron into plumbago, and that corrosion depends upon the want of homogeneousness of the surface, or upon its density or hardness, or upon the combination of the carbon with the iron.

This subject was very thoroughly discussed by some of the most eminent engineers of the London Society in 1862, and numerous cases were cited both of corrosion and its absence in iron under water, and the causes explained.

The examples then stated, and numerous others, showed that cast-iron of a particular description corroded rapidly, or changed its structure, by a few years' immersion in foul or salt water, while other irons were entirely unaffected when exposed in the same way for twenty, thirty, and forty years.

In the same structure, as in the case of the iron gates of the Sheerness Dock, three pairs of gates had resisted the action of salt water for forty years, and a portion of the fourth pair, put in several years later, had been much softened and injured by its exposure.

Several of the leading engineers instanced numerous cases of square cast-iron piles, standing partly in and partly out of salt water, and a portion alternately wet and dry at each tide, which, after periods of eighteen, twenty-four, and thirty-one years, and intermediate periods, showed no signs whatever of corrosion or change—"the square angles of the iron were as sharp as when they left the foundry."

Mr. Simpson, the past president, said that in his practice he used great care in the selection of the iron, and such iron was practically uncorrosive.

The members stated, that wherever this corrosion or decomposition had occurred, it was wholly due to the quality of the iron. The engineer has, therefore, only to select that of a proper quality to insure durability.

My own experience and examinations, so far as they reach, confirm these opinions.

Cast-iron, to resist corrosion to its greatest extent, should be as hard as the case will admit, of an even, close grain, and with the carbon combined and not in the form of graphite. Impure, soft foundry iron will corrode rapidly; close-grained gray iron, of an even texture, will resist corrosion in the most exposed places without sensible injury, and white iron of good quality may, for all practical purposes, be considered as imperishable in such situations.

Care should also be taken not to place iron in contact with other metals, so as to produce galvanic action.

It is well known that many cast-iron water mains have corroded greatly, not only externally but internally. In the latter case, the oxidation sometimes takes the tubercular form, where the rust is collected and aggregated in hard knobs.

In the early manufacture of water-pipes, they were often made from the worst quality of metal; it could hardly be called iron, but was a composition of cinders, sand, scoria, and iron of the softest kind, loose-grained, and in large crystals; indeed, precisely such a mixture as would offer the least resistance to corrosion.

Water-pipes placed in the streets of a city in earth alternately wet and dry, and saturated with mephitic gases from sewers and gas-pipes, are exposed to corrosion more than under almost any other circumstances, and, if made of the material just stated, will be destroyed, where those of a proper quality of metal would endure a very long time. The in-

ternal corrosion, however, where the iron is exposed only to the action of pure water and a small amount of air in combination, will not occur to any appreciable degree, if the iron is of the proper quality.

The strength of cast-iron pipes, of the usual thickness, is so far beyond the pressure of the water and occasional percussions, that the manufacturers seem to think that the weakest metal will answer ; and the engineers have not yet, in their specifications and inspections, required enough care in the selection of the metal best calculated to withstand corrosion.

## IV.

### DURABILITY OF CAST-IRON WATER-MAINS.

(*Extract from a Letter from* James B. Francis, *Civil Engineer*, *27th July*, 1868, to A. W. Craven, *Member of the Society.*)

I took up some eight-inch cast-iron pipe last year, which had been in use since 1828. It was made in Philadelphia, and laid in the mill-yard of the Merimack Manufacturing Company, in connection with the force-pump, for fire purposes. Until 1849, the head did not much exceed 150 feet ; since then it has been about 200 feet, exclusive of the effect of water-hammer.

The interesting point, however, is its state of preservation. Thinking it might be of interest in connection with the proposed discussion, I send a section of the pipe. When taken up it was lined with tubercles, projecting say $\frac{1}{4}$ to $\frac{1}{2}$ of an inch. As the pipes were intended to be relaid, and in fact have been except two or three pieces, they were scraped out. The outside remains pretty much as when taken up, except as the rust has jarred off in carting the pipe. Thirty-nine years' use appears to have made but little impression upon it.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

V.

## HISTORICAL SKETCH OF THE SUCCESSIVE IMPROVEMENTS IN SUSPENSION BRIDGES TO THE PRESENT TIME.

A Paper read before the Society, March 18th, 1868, by CHARLES BENDER, Civil Engineer (formerly Assistant at the Polytechnical University at Karlsruhe, in Germany).

In the present day of long-span bridges, more particularly those of suspension, across the wide rivers of this continent, it may not be uninteresting to the civil engineer to trace the successive improvements in their mode of construction, and to fix definitely the claims of inventors and designers to such improvements as they may be respectively entitled to. I am not aware that the subject has been treated in this light before, and therefore, in view of its importance, make no further apology for occupying your attention.

I found in an old book the following sentence :

"The invention of the suspension bridges by Sir Samuel Brown sprung from the sight of a spider's web hanging across the path of the inventor, observed on a morning's walk, when his mind was occupied with the idea of bridging the Tweed."

The artificer of the web who really guided Sir Samuel Brown, was the *American engineer James Finley*, of Fayette county, in the State of

Pennsylvania. He, in the year 1796, built the *first regular* suspension bridge across *Jacob creek* on the turnpike from Uniontown to Greensburg, in the State of Pennsylvania. He obtained the first patent on this object from the Government of the United States, and the book, "Treatise on Bridge Architecture, by Thomas Pope," published in New York in the year 1811, spread this ingenious invention over the whole world. Some English and French authors, and even Pope, tried to diminish Finleys's merits by attributing this invention to the Chinese and Indians, but these people used only ropes or common chains, fastened to trees, and the path was directly on the catenary, without suspended floor.*

The development of the art of bridge-building is showing and proving how deeply James Finley had studied his task, and how much we owe to him.

The principal features of his invention consisted in the application of artificial stone abutments, in the introduction only of two chains, one at each side of the bridge, the links of which were as long as the distances between the cross-bearers or joists. Finley applied one-seventh of the spans for the deflections of cables, introduced suspension rods and stirrups to support the joists, and arranged the anchor chains at the same angles as the main chains, to avert powers acting to throw down the piers.

The most interesting of the novelties, and one upon which Finley apparently laid a great value, was the arrangement for distributing the load over a great extent of the bridge, thereby aiding to divide it over many suspenders, and to stiffen the otherwise movable floor against change of shape.

His specification reads as follows :

"To bind and connect the whole that they have the same effect as a *platform of one piece*, four or more joists will be necessary for the upper

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* At the discovery of America similar constructions were found there.

*Humboldt* found in the year 1802 a suspension bridge across the river Chambo, in Peru, the ropes being three feet thick, made of roots of the *Agave Americana*. The span was forty feet.

In the year 1515 the Landsknechte, a kind of regular troops (Germans and Switzers), built a rope-bridge across Padus river, in Italy, which they passed with artillery.

In the year 1595 Admiral Coligny, in France, made a rope-bridge near Poitier.

In the year 1734 the army of the Palatinate of Saxony, in Germany, built a *chain* bridge across the Oder river, near Glorywitz, in Prussia.

The bridge across the Tees, in England (1741), seventy feet long and two feet wide, was like those constructions in *China and Thibet*, having chains fastened to timbers, the planks laid on them directly.

tier—to extend from end to end of the bridge ; each will consist of more than one piece, the pieces had best *pass each other side by side*, so that the *ends may rest on different joists* on the lower tier. The splice will then extend from one joist to another of the lower tier, and must be bolted together by one bolt at each end of the splice. The planking floor is laid on the upper tier."

Herewith the inventor formed strong beams, continuous from one end of the bridge to the other, and the continuity itself gives the utmost certainty, that these beams, which were no directly bearing parts, had the aforesaid important object, to stiffen the floor, prevent greater changes of form, or in other words to neutralize the momentum, arising from loads and wind.

The method employed was sufficient for the spans at that time in use, and in connection with the stiff railing, fulfilled entirely the conditions necessary for a good bridge for common traffic. For the time in which Finley lived, his bridges were astonishing structures in reference to the insufficient knowledge of the art of frame bridge building, and spans of three hundred and six feet at the commencement of the nineteenth century, appear bolder than twelve hundred feet in our days.

We can learn by studying Finley's plan how the neglect of his well-founded directions caused many disasters to suspension bridges.

It is astonishing how few understood him. Instead of keeping the stiffening continuous beams, and instead of proportioning the same according to the spans and loads of the bridges, it was believed to be an unnecessary weight and increase of cost of bridges ; and instead of adapting great deflections of cables or chains, it was believed to be a better arrangement by taking flat arcs, and deflections equal to one fifteenth of the spans, whereby the cost of the bridges became nearly double as great as before.

Up to the year 1801, according to Finley's patent, eight bridges had been built in the United States, and there were added forty others between the years 1801 and 1808. The largest of all was the Schuylkill chain bridge, of three hundred and six feet span.

It is not uninteresting to know the names of some of the first buildings of this kind.

The *Potomac Bridge*, near Washington, had one hundred and thirty feet span, its floor being fifteen feet wide ; the *Cumberland Bridge*, in Maryland, had the same span ; the *Brandywine Bridge*, near Wilmington,

was built with one hundred and forty-five feet span, and a thirty feet wide floor, and two other bridges were built of one hundred and twenty feet span each, at *Brownsville*, in Fayette county, in the State of Pennsylvania. A bridge across the *Merrimac*, three miles from Newburyport, in the State of Massachusetts, carried out by an engineer named *John Templeman*, of the District of Columbia, is more particularly described, and is one of the most interesting buildings in the history of bridges. The span of this bridge was two hundred and forty-four feet; the abutments forty-seven feet long and thirty-seven feet high, were made of good masonry. The two roadways, of fifteen feet width each, were strong enough to allow for the passage of horses and carriages, whatever their speed. Ten chains, each five hundred and seventy-six feet long, were made to bear five hundred tons with perfect security. Three of the chains were fastened on each side of the bridge, and four in the middle. "The railing was stout and strong," a construction which "contributed much to the stiffness of the floor." Thomas Pope himself calls it a wonderful structure, describes the railing as contributing much to the stiffness of the floor, and states that Templeman's talents and improvements had earned for him a great reputation as engineer of such work. He also reported that the motion of the floor of the Merrimack bridge was "*very little perceptible*, whatever the *speed of any kind of traffic.*"

The bridge across the *Lehigh*, built in the year 1815, near *Northampton*, in Pennsylvania, consisting of two whole and two half spans, four hundred and seventy-five feet long, bearing two tracks for carriages and two six feet wide footpaths, was the *first mentioned* suspension bridge of more than one span.

The *application of wire for suspension bridges* is also an American invention, for the first wire-bridge was built *before* the year 1808, at *Philadelphia*, across the Schuylkill river, with a span of four hundred and eight feet. I found in the book on wire-bridges, by the French engineer, Seguin, published in the year 1824, that a report on the American canals, written by Mr. Galatin, in the year 1808, and copied in a French book from the year 1820, mentioned the wire-bridge at Philadelphia. The same bridge is also described in the "Bulletin de la Société d'Encouragement," in the year 1816.

According to these notices, the existence of the American wire suspension bridge was well known in Europe a long time before the first regular suspension bridge was built there.

Pope's book was well known in France, and Seguin, as well as the famous French engineer, Navier, made use of it. Finley's important invention, in connection with Templeman's improvements, as well as Pope's book, and the wire bridges built in this country, were known in England by Samuel Brown and others in the year 1814, and it is most probable were known in France, for the brothers Seguin, French engineers, seem to have been in England, and Navier especially was sent there to study suspension bridges.

At that time a Frenchman of the name of *Poyet* proposed a kind of stay-bridges, consisting of high wooden masts as towers, from the tops of which were starting many stays to both sides, supporting the floor.

But the English engineers were the first who proposed and applied stays for suspension bridges, in connection with cables, as well as without them.

The first of these bridges was built by Richard Lees, at *Galashiel*, across the river Gala, in the year 1816, of a span of one hundred and twelve feet; it was like the two following, a wire-bridge. The bridge at *Kings-Meadow*, across the Tweed [span one hundred and ten feet], was built in the year 1817, and another structure at *Thirlstone Castle*, one hundred and twenty-five feet long—both with stays. At Kelso, on the Tweed, a bridge of three hundred feet span was built for carriages—the roadway eighteen feet in width. A bridge at *Dryburgh-Abbey*, with stays, was two hundred and sixty feet long, and very movable; so much so, that four persons could shake it so as to break one of the stays. In the year 1818 a wind destroyed the whole structure. Rebuilt according to Finley's system, provided with strong longitudinal beams, strong railings and anchors, like those at Niagara bridge, it resisted the obnoxious motion. Especially is it stated that the *railing resisted all upward movements*. The use of anchor-chains, to prevent side and upward movements of the floor is, therefore, already very old, and Sir Samuel Brown often made use of them.

The bridge at Dryburgh is interesting in another reference, as it is the first wherein the chains were convergent in the middle of the span. At the towers of this bridge the distance apart of the cables was twelve feet, and in the middle of the bridge it was only four feet; the object being to reduce the side motion. But the engineer, *Stevenson*, already observed that he preferred to keep the parallelism of chains, and rightly, as I hope fully to convince you in a future communication.

A great many of the stay-bridges broke down, and after many sad experiences, the use of stays has been entirely rejected by English engineers, notwithstanding they have been reintroduced into this country.

Navier saw different bridges built by Brown in England, and he describes the action of the stays in aiding to support the floor; others were introduced horizontally, but inclined to the longitudinal axis of the bridge, to reduce the side motion, and he criticised sharply the combination of stays with suspension rods and chains or cables.

The use of separate tension cables attached to the two towers, working horizontally or vertically against the action of the wind; the application of pendulums to support the cables on the pillars, allowing expansion and contraction of cables, are ideas of the famous engineer *Brunel*. These applications are made at Brunel's bridge on the *Island* of *Bourbon*, and are copied at the suspension bridge across the river Meuse, at Liege, in Belgium, and at the Alleghany bridge near Pittsburg.

*Telford*, the engineer of the *Menai Straits* suspension bridge in England as far as I can learn, added the improvement of saddles on rollers, supporting the cables or chains, to allow for the movements in case of change of temperature. The railing of this bridge was proposed six feet high, the span being five hundred and sixty feet.

I have mentioned that by the French government, in the year 1821, *Navier* was sent to England to study the existing suspension bridges, and to report on the same. He collected the different historical notices, described Finley's and the English bridges, and gave the theory of movable suspension bridges in his classical book, published in the year 1823. The curve of the suspension cables when loaded, Navier first regarded as parabola, rejecting the complicated older formulæ as given by Jacob and John Bernouilli, Huyghens, Euler, and others. It is to be regretted that this celebrated and highly scientific man, overlooked the influence of wind acting from below on the floor, and thus becoming the most dangerous element to destroy suspension bridges. Indeed, Navier's theory and his reputation contributed much to the false judgments about Finley's improvements, and caused the error of introducing *small deflections* and of omitting the *American longitudinal beams and railings*, these important stiffening elements, which, in the right proportions, are inseparable from any good suspension bridge.

Finley expressly advocated the construction of *platforms of one piece*, but Navier and his followers supposed a *perfectly movable floor*. Finley

applied $\frac{1}{7}$, Navier, $\frac{1}{12}$ to $\frac{1}{15}$ of the spans for deflections. Finley prevented the undulations by his stiff platform; Navier believed he could prevent greater displacements by flat catenaries. This is the great antithesis of these two celebrated engineers, and every scientific bridge builder must concede that Finley stood much nearer to the perfect solution of this problem than Navier.

But notwithstanding Navier's book was of great value to science, and he opened for investigation many interesting questions.

Navier paid attention to the effect of change of temperature on suspension bridges, and after having examined the use of rollers on the towers, he gives some hints about the effect of the same forces on the platforms, which he supposes to be movable. His own words in this respect are:

"By applying continuous longitudinal pieces in the platform of the bridge, it will be necessary to compound these pieces of parts connected by *joints*, which *leave a little freedom*, so that the adjoining parts *can slip* on the others, where the *heat* is lengthening the same."

But it is not to be understood that Navier meant to apply such slip-joints to the chords of a truss, for in our climate such a truss would not begin to work before it was bent to deflections equal to about $\frac{1}{60}$ of the span. Hence, it follows that if such a truss with slip-joints were applied to a suspension bridge, it would not work at all, but merely act as a dead weight.

In the same classical book, Navier describes the *suspension canal-bridge*, built by *Count Chabrol* in the department of Puy-de-Dôme, in France, the length of which was six hundred and fifty feet, and he gives calculations and plans of a project of this kind. These ideas and plans have been applied in constructing the Pennsylvania canal-bridge for spans of one hundred and sixty feet.

The first suspension bridge on the continent of Europe was built in the year 1823, at *Geneva*, in Switzerland, by *Colonel Dufour*. It was a wire bridge.

In the year 1824 the elder *Seguin* published the first edition of his work on wire bridges; a book important in many respects, giving many new ideas and improvements.

There the utility of the stiffness of the platform of suspension bridges was not overlooked, as was done by Navier and the English engineers. On the contrary, the meaning and the importance of stiff railings as well as of longitudinal beams were fully appreciated.

I must not omit to translate a portion of this work, throwing light on the fact, that James Finley and Templeman are to be regarded as inventors and improvers of suspension bridges with stiffened floors, rejecting all later pretensions and claims of this kind.

In this aforesaid book is to be found:

"One of the greatest inconveniences of suspension bridges are the vacillations arising from moving loads of any considerable masses. To prevent these, there should be employed all possible means affording rigidity; the very best of all existing of which I know is the arrangement of *strong trusses as parapets of the bridges.* These have to consist of *long pieces of wood* forming the *frames*, and of wooden *Andrew crosses* put together at *right angles.* The connections of the different pieces should be made by *iron bolts*, piercing the *frames or chords between the joints of the diagonals*, allowing any desired tension and great rigidity."

Further Seguin says:

"The first quality of the floors or platforms of suspension bridges is to have as much rigidity as possible, and to obtain it care is to be taken to fasten together the different parts, so as to get a continuity preventing any separation. It is customary to attach the suspension rods *to* cross-bearers which are supporting the floor itself, but it is possible as well to apply longitudinal pieces to support the cross-bearers, and it seems to me to be far preferable to establish in all cases longitudinal flooring before cross-bearers. The longitudinal pieces had to be of the greatest possible dimensions, their joints to be well connected to avert those horizontal movements, which are consequences of the deficiency of continuity in the floor."

"*The Americans had adopted* $\frac{1}{7}$ *of the spans for deflections of cables. This disposition, being very favorable in reference to solidity, is inconvenient in regard to displacements, which become always the less the more the deflection of cables is diminished. But the Americans have neutralized that inconvenience by adding to the floors great masses, and using strong railings, to increase the rigidity.*"

Concerning the said masses, Seguin meant evidently Finley's longitudinal and continuous beams, laid on the cross-bearers; the weight and action of which reduced the side motions caused by wind, and which had, besides this effect, the more direct object which Seguin mentioned before, but did not understand fully. Navier's influence on Seguin is evident already.

The brothers Seguin introduced the method of boiling the wire in oil, thus giving a good coating as a preventive of rust. But they observed that the wire after the process of boiling, lost a portion of its strength, an observation which is confirmed by newer and very minute experiences of reliable men.* Indeed, the temperature of boiling linseed oil is at six hundred degrees Fahr., which is the same temperature required to soften steel, at which that dark-blue color, so characteristic of the tempering of steel, is observable.

The method of covering the chains with white instead of any other color, as was Finley's practice, is first mentioned in the description of the *Hammersmith bridge*, in England. The same Hammersmith bridge, as seen in the year 1854, was stiffened horizontally by cast-iron beams, suitable chords and diagonals, and the vertical movements were prevented by strong railings. This was perfectly sufficient for common traffic, and the Hammersmith bridge was celebrated for its good proportions and strength.

Many bridges of this time suffered by gales of wind; many of Brown's structures, and generally those near the sea, and more especially those constructed with stays, were destroyed entirely; others badly damaged.

*Telford's Menai bridge*, for instance, was extensively injured, and the engineers fell into the great mistake of preventing the undulations and motions, caused by wind, by increasing the dead weight of the bridge itself. The floor of the Menai bridge has a weight of ninety-seven pounds per superficial square foot. But the evils of this system soon produced a change in the opinions of the engineers, and it was the engineer *Rendel*, to whom was confided the repair of the suspension bridge at *Montrose*, who was induced to apply a good method of stiffening the floor of suspension bridges. Though undoubtedly Finley and Templeman are to be regarded as the first constructors of stiffened suspension bridges, as we well know, and as Rendel's method is merely one of its applications, yet the ideas in that time were disturbed to such a degree, that he is to be regarded as the true reformator of suspension bridges, and as the man who again brought to clear understanding the idea of longitudinal beams and trusses reaching from one end of the bridge to the other. Rendel also condemned more decidedly the use of stays, and proved by fact the truth of his judgment.

* Experiments by Professor Karmarsch and Engineer Brix, in Prussia.

This bridge of Montrose was built in the year 1825, by Samuel Brown, its span being four hundred and thirty-two feet, deflection of cables equal to forty-two feet, and width of floor twenty-six feet. In the year 1838, the platform was destroyed by a heavy gale, and in the year 1840 the chains gave way with a load of seven hundred men on the floor, whereby a considerable loss of life was caused.

Rendel, in his report, says :

"In the anxiety to obtain a light roadway, mathematicians, and even practical engineers, had overlooked the fact that when lightness induced flexibility and consequently motion, the force of momentum was brought into action, and its amount defied calculation."

"The author has long been convinced of the importance of giving to the *roadway of suspension bridges the greatest possible amount of stiffness in such a manner as to distribute the load or the effect of any violent action over a considerable extent.* The platforms of large bridges in exposed situations are acted upon in so many different ways by the wind, that he had *an objection to the use of stays or braces to counteract movements which ought rather to be resisted by the form of the truss-structure.* Holding such opinions, he determined to adapt a *framing, which, although connected rigidly in every direction, should nevertheless be simple, composed of few parts, capable of being easily renewed, should distribute its weight uniformly over the chains, not be subject to change from variation of temperature, and not augment the usual weight of suspended platforms.*"

According to these principles, which are embraced entirely in the old American inventions, but more defining the same, Rendel repaired the Montrose bridge in the following way : "Instead of cast-iron cross-bearers, he adopted wooden joists thirteen feet by three and a half feet, bolted together and trussed with a round bar of one and one-eighth of an inch diameter ; every sixth beam had a deep-trussed frame on the under side, so as to give great stiffness above and beneath the cross-beams ; on each side of the carriage-way were bolted two sets of longitudinal timbers, four in each set ; they were further united by cast-iron boxes at intervals of ten feet. A curb of timber eleven inches by six inches was attached to the ends of the cross-bearers, and extended the whole length of the platform. To add to the stiffness afforded by this construction, the author caused to be passed through the spaces between the pair of longitudinal beams, a series of diagonal truss-pieces of timber, six inches square, with the ends stepped in the cast-iron boxes, which at every ten

feet grasp the beams. On the other end of these diagonal truss-pieces, an iron screw bolt one inch and a quarter diameter at every ten feet, and a contrivance of wedges in the cast-iron boxes, enabled any degree of tension to be given to the framing. The roadway was thus stiffened by two of the strongest kinds of framing in parallel lines, dividing the carriage-way from the footpaths."

This truss work, with the perfect understanding of the working momenta, was expressly made to resist flexures upward as well as downward, an arrangement omitted in one of the greatest existing constructions.

The requisite horizontal stiffness was obtained in the following way: "The carriage-way was formed of four thicknesses of Memel planks, the two lower layers, each two inches thick, were placed diagonally with the transverse beams crossing each other so as to form a reticulated floor, abutted against the longitudinal beams. They were firmly spiked to the beams and to each other at all the intersections, and upon them was laid and spiked a longitudinal layer of planking two inches thick. Each layer was closely jointed and caulked, and the upper one was laid in a mixture of pitch and tar; a composition of fine gravel and sand cemented with boiled gas-tar was laid over the whole, to the thickness of one inch, forming the road track."

The absence of Brunnel's counter-chains and of Brown's counter-stays, and other unnecessary and even dangerous furniture, is to be regarded as highly commendable.

"The whole formed a compact mass of braced wood work, the diagonal planking giving the horizontal stiffness, and the two trussed frames insuring the vertical rigidity."

It is interesting to know the weights of this structure, as important concerning the art of building suspension bridges with stiffened floors.

| | | |
|---|---|---|
| The weight of the roadwork was | 131 tons. | Per running foot, 0.53 tons. |
| " of cast and wrought-iron | 37 tons. | |
| " of suspension rods | 21 tons. | |
| " of fencing (wrought-iron) | 9 tons. | |
| " of gravel concrete | 30 tons. | |
| Total | 228 tons. | |

or forty-seven and a half pounds per superficial square foot, for the entire roadway. Subtracting the gravel concrete, it is forty-one pounds. Before

the bridge was stiffened, the weight was forty-four pounds per square foot.

The bridge has borne without injury heavy gales, as could be foreseen, and the stiffness has given confidence in the strength to all who have examined it.

The English engineers agreed with Rendel, and the engineer Vignoles eulogized this excellent communication for the practical conclusions which it contained. "He found it not difficult to foresee, that by carrying out the system of *adopting well-trussed framings* to the platforms of suspension bridges, *sufficient rigidity* would have been obtained for *locomotive engines and carriages on railways* to traverse rivers or ravines by means of these bridges, instead of the costly viaducts or heavy embankments; and Mr. Rendel saw no difficulty in giving any required amount of rigidity to the platforms; it was only necessary to increase the strength of the framing, to enable the roadway to bear with perfect safety the passage of an engine and a train of carriages."

In the mean time the wire bridges found a favorable reception in France, which is full of admirable structures of this kind, and the French engineers brought the manner of constructing cables to the high degree of perfection of our day.

After the preceding introduction of wire bridges in England and Switzerland, the brothers Seguin constructed the first wire suspension bridge in France, in the year 1824. All the existing methods of splicing wire, of bringing up the cables, have been studied, and theories of great mechanical value have been invented.

The cables were first made on land and then carried on the towers by machinery, but soon the French engineers began to build them on the towers themselves. Very perfect methods have been employed, securing all possible equality of tension in the single wires; and as greater perfection always requires more time and trouble, these methods are more expensive than those of a later origin, which, shortening a little the time of construction, are not securing the same equality throughout.

Now, the time to make a wire cable of one thousand six hundred feet length, is about *one year*, which involves *a great loss when we consider that steel chains can be obtained cheaper, much more secure, much lighter and better*, than any wire rope can be, and by the use of which *the time for building* suspension bridges is *considerably reduced.*

Such a steel chain bridge was built in Vienna in the year 1829, by

the *Austrian engineer Mitis.* It is praised in all reports as a strong structure.

The wrappings of the French cables are made at intervals of about one foot ; in later times the wrappings have been made continuous.

*In the year* 1831 *the French engineer Vicat*, in his report on the suspension bridges across the river Rhone, described his method for building wire-bridges in place, directly on the towers and abutments, a method which, essentially in the same manner, was copied by erecting the Niagara and Cincinnati bridges. This method is described as follows :

"The towers and abutments of a suspension bridge being finished, the points of attachment ready to receive the cables, and supposed that a number of double wires of equal lengths, forming circuits, are wound on different reels, these *wires are drawn from one pillar to the other by means of a thin endless rope*, like the guide-rope of a flying ferry, and moved liko the *chain of a chain-pump.*"

By this method Mr. Vicat proposed to make and suspend cables, with less cost, with fewer workmen, and in shorter time than before. He said it was not difficult to reduce *the number of cables to two*, if it was desired, whereby the surface exposed to oxidation would be diminished ; the tension of the single wires would be uniform, whatever the thickness of the cables ; the apparatus for elevating the cables be simplified, and the greatest possible spans would be admissible.

More details on this subject can be found in the article on the bridges across the river Rhone in the French "Annales des Ponts et Chaussées," 1831, volume first.

*Mr. Chaley*, the engineer of the celebrated suspension bridges at Friburgh, in Switzerland, worked out Mr. Vicat's method, and often had occasion to apply it. He, according to the same method, built the second suspension bridge at *Friburgh*, in Switzerland ; further, the bridge "*de la Charité*," across the river Laire, a suspension bridge in *Paris*, another at *Percey*, in the Jura mountains, and the bridges at *Cormery*, across the Indre, and of *Beaumont*, across the Sarthe, in France.

Vicat's method was further employed at a bridge at Tours, in France, for transporting materials. Interesting details are found in the "Annales des Ponts et Chaussées," year 1841.

Other methods for constructing the cables of suspension bridges

directly on the towers and abutments, are that of the French engineer *Le Blanc*, constructor of the splendid bridge at *Roche Bernard;* and, after him, that method introduced by the French engineer *Le Clerc*, the constructor of the suspension bridge at *Lorient*, across the Scorff. The anchorage of these bridges (the first is of 643 feet span, the other 610 feet) is interesting, as the cables form one continuous belt, laid around the abutments in suitable vaults, allowing free circulation of the air, as well as to repair the painting of the wire from time to time. The two cables, at both sides of these bridges, have the *same deflections*, an arrangement which is not objectionable. (The description can be found in the "Annales des Ponts et Chaussées," 1850.)

The French methods and designs have been used in our country; especially the method of constructing the cables directly on the towers, in the year 1844, at the Alleghany suspension bridge, near Pittsburgh, and Vicat's invention was a little, but not essentially, modified at the construction of the Niagara and Cincinnati suspension bridges by Roebling.

A picturesque suspension bridge is that at *Cubzac*, across the river Dordogne, in France, with five continuous spans of 363 feet each, the towers being constructed of iron (iron towers 82 feet high; total height of towers above low water = 126 feet).

Iron towers also are used at the chain bridge at *Seraing*, in Belgium, and at the chain bridge at *Muehlheim*, on the Ruhr, in Prussia.

Since the accident of the wire bridge at *Angers*, in France, in the year 1850, many of the wire bridges in Paris have been replaced by truss and arch structures, and a law is introduced directing tests of wire bridges from time to time. During such a test in the year 1861, the suspension bridge at Mirabel sur L'Eggues broke down, the cable having been destroyed by rust in the interior.

The elder *Seguin* in *the year* 1840 had an opportunity to apply the old American method of stiffening suspension bridges, which he appreciated highly, as has been demonstrated. *He was the first man, at least in Europe, who built a suspension bridge for railway purposes, and with full success.*

His work was an auxiliary suspension bridge across the *Soane* river, built in the year 1840, when some spans of the wooden railway bridge were swept away. The two spans of his bridge were 137.5 feet each, the deflection of the cables was 16⅔ feet, girders 8½ feet high, composed

of wooden beams 9 inches by 2½ inches, and chords of 13 inches by 6½ inches, connected with the longitudinal beams of the floor by screw-bolts, and kept in vertical position by braces, were to stiffen the floor vertically. The three cables on each side were connected by numerous ligatures. This new bridge was reported to have been *as stiff as the former truss bridge*, and was used as a railroad bridge during four years with perfect success, and then the remaining wooden frame bridge as well as the suspension bridge were replaced by a stone structure.

This bridge also had neither stays to support the floor, nor stays to add for horizontal stiffness.

Our vice-president, Mr. Julius W. Adams, kindly showed me a plan of a stiffened railroad suspension bridge across *Kentucky river, at Frankfort*, which he passed *over in the year* 1852. It had been built some years previously, but precisely when, or by whom, he was unable to ascertain. It is possible that it was built before Seguin's structure. Besides this, it had also no stays. The spans of this stiffened suspension bridge were one hundred, two hundred and sixty-one, and two hundred feet, the lattice girder was six feet high, the distances of suspension rods and like-wise of the cross-bearers equal to three feet, and floor with girders had the calculated weight of nine hundred and thirty pounds per lineal foot.

In the *year* 1842, the *Austrian engineer*, *Schnirch*, who built the well-known suspension bridge at *Prague*, proposed a new system of suspension bridges, the curves consisting of two pairs of parallel chains, one above the other, and both connected by triangular trussings. At these bridges the chains themselves represent a stiff inverted arch, and are to be calculated only as such. A bridge of this kind, before Schnirch had occasion to introduce his system in practice, was carried out in Switzerland, across the river *Aar*, near Aarau, but the distance of the chains was too small to be considered as sufficient.

*Schnirch's* plan was carried out for two tracks in *Vienna*, in the *year* 1861, to bridge a canal of the Danube river. As Schnirch's plan is of so old origin, and an ingenious invention; and as the suspension railroad bridge in Vienna is, until this day, the best, though not the longest stiffened suspension bridge, I will proceed to describe it.

Two parallel chains on each side, consisting of alternately eight and nine link-plates each, are placed at a distance apart of 4.1 feet. The trussing consists of a single triangular system, the diagonals being 6.4

feet long, the links of the chains are ten feet long, and six by 1.35 inch and six by 1.16 inch, respectively; two pairs of chains, in a distance of thirty-one feet from centre to centre, limit the floor sideways; four longitudinal trusses of wrought-iron, consisting of uprights and crossing diagonals are made to stiffen the floor and to offer suitable points of attachments to the suspension rods, at distances of about five feet. The suspension rods themselves are made adjustable. The longitudinal trusses are 2.5 feet high, and represent likewise the chords for a horizontal trussing, the uprights of which are the cross-bearers, iron girders of 2.5 feet height, and the diagonals are strong iron bars, fastened by rivets.

The span is two hundred and fifty-two feet; anchorage, architecture of piers, and performance are entirely successful.

Though this bridge has no great span, it is to be regarded as the best and most complete, in point of principle, of all existing suspension bridges. I, therefore, believe it is an act of justice to give to a man of the originality of Mr. Schnirch the honor which he has a right to claim.

During this time the American engineers, occupied in improving the wooden truss-bridges, did not forget to appreciate suspension bridges, and that they constructed the greatest spans is well known. I mention the former Niagara bridge, of one thousand and forty-two feet span; Ellet's Niagara bridge, of seven hundred and sixty feet; and the unfortunate Ohio bridge, at Wheeling, of one thousand and ten feet span. The latter, without any kind of stiffening, succumbed to a heavy hurricane, in the year 1854. Stays would not have prevented this accident, for, under the same circumstances, stays were rejected at an early day of this century.

At the time when the *Britannia tubular bridge* was to be built, *R. Stephenson* proposed a stiff suspension bridge, in form of an iron tube, suspended by chains. Many and costly models were built, as at this time no theories existed either of truss or of suspension bridges. The tubes in these models were made stronger and stronger after every experiment; and, lastly, the chains were no longer necessary and were dispensed with, and the iron tubular bridge was the result.

It is plain that the Niagara railroad bridge is the direct application of Stephenson's plan.

This work, as well as the Cincinnati bridge, is sufficiently known,

and therefore I do not consider it to be necessary to describe them, nor to demonstrate that they are to be appreciated as great works of American enterprise and boldness, but exhibit nothing commendable in the way of *invention*.

Before finishing this short sketch of the history of suspension bridges, I have still to mention that the third possible arrangement to stiffen a suspension bridge was carried out in London in the year 1862 by the engineer *Barlow*, who bridged the Thames by three single spans of two hundred and eighty feet each. This work is named the *Lambeth Bridge*.

The said system consists of cables, horizontal beams, and uprights, with diagonals between the cables and beams, so that these represent the chords of the truss work. This arrangement is the most objectionable of the three possible manners of stiffening suspension bridges.

The detailed construction as furnished by Barlow is unnecessarily complicated, and the tube, this favorite monster of English engineering, is not forgotten.

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Notice.—Members receiving the Transactions are requested to advise the Secretary thereof, and to notify him of change of residence

Society Rooms, 11 and 12,
No. 63 William Street,

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

# TRANSACTIONS.

## VI.

ADDRESS of Hon. W. J. McALPINE on assuming the Chair after his election as President of the Society, September 2, 1868.

GENTLEMEN :—In accordance with the custom of societies of this character, on taking the chair I have prepared an address, in which, after some personal preliminary remarks, I have called attention to the benefits and advantages of our Society to the profession in this country, and have made some suggestions, which will, I think, promote its usefulness ; I have also called attention to the effect of similar societies elsewhere, in advancing the dignity and influence of the profession, as well as the individual interests of the members.

I have made a brief statement of the advancements in engineering within a recent period, and the immediate application of all of the discoveries in the kindred sciences to the purposes which the engineers may have had in hand.

I am very much gratified with this mark of your kindness, in placing me at the head of this Society, an honor which I feel that I owe to your partiality towards me, although I am a non-resident member.

It is well known, I believe, that I earnestly recommended the selection of a resident member to fill the vacancy caused by Mr. Kirkwood's

resignation, and that I stated that my engagements for some time hence, would keep me from New York, and prevent as much attention to the duties of President as the interests of the Society demanded.

You have overruled these objections, and I therefore most cheerfully undertake the duties, with the renewed pledge to do all in my power to advance the interests of the Society, and promote a cordial feeling among the members.

I need hardly remind you, gentlemen, that our Society cannot continue prosperous by the exertions of any small number of its members, however zealous or influential they may be.

If we are to succeed, it must be by the united, cordial, earnest efforts of a considerable number for the next two or three years ; and I therefore most earnestly urge this zealous co-operation in all of the measures which have been inaugurated, or which may be adopted for promoting the objects of our association.

The cultivation of a cordial and fraternal feeling is equally necessary, and will render our meetings a source of pleasure as well as of profit.

The true engineer loves, and is devoted to his profession. He believes it to be "the noblest of them all," giving scope to higher and deeper thoughts, and wider range for the intellect, but especially to those thoughts which are immediately beneficial to mankind.

Our Society has been established for the purpose of advancing knowledge, science, and practical skill among its members, by an interchange of thoughts, studies, and experiences.

The necessity of a Society to promote these objects has been long acknowledged, and many attempts have heretofore been made to form one.

The original efforts in behalf of our own institution *ought not to have failed.* It embraced almost all of the engineers in and near the metropolis, and some from the interior. They entered upon the project with a zeal and earnestness that deserved success. Less than a dozen of our present members struggled on manfully for a couple of years, but the task was too onerous for them unaided by the others, and they had finally to yield to untoward circumstances, and for ten years the Society slumbered.

I take shame to myself for neglecting my duty in that struggle.

Absorbed in the care of important works at a distance from New York, I did not then realize the great benefits which I might have received from the Society.

Others from the interior, like myself, were also absorbed, each in his individual works, and did not perceive that we could lighten our labors, increase our knowledge, and secure better success in our various undertakings, by associating with those engaged in kindred pursuits, some of whom were working out singly the same problems.

This Society has cause to remember with gratitude the valuable services of our first President, Mr. Laurie, and among other things for his care of its funds, which, under his judicious management, were doubled.

In less careful hands they might have been improvidently expended, or proved only a "buried talent."

To our zealous and faithful Secretary and Treasurer, Mr. Morse, is also due our grateful thanks.

And while on this subject, it is proper to add the names of the early managers to whom I have alluded, our late President, Mr. Kirkwood, Messrs. Talcott, Adams, Craven, Greene, Copeland, Swift, Ford, and Smith, and some others.

Our revived Society has been nearly a year in operation, and it now devolves upon the present members (including those already named) to determine whether it shall be successful.

With the funds which have been so carefully preserved we have fitted up these convenient rooms, and offer them to the use of the whole profession when visiting New York. It is intended to make them the "chamber of engineering," where those from other cities and the interior, during their sojourn in town, may daily meet—not the local members alone, but other visitors—where, if they desire, they may introduce for discussion any engineering question ; where they can leave on the "Visitors' Record" their city address, and ascertain the addresses of other visitors to the city, and where gentlemen, desirous of meeting engineers on business, may hear of and from them.

A desk and other conveniences are at the service of any of the profession, and we shall never feel more happy than when our rooms are thus availed of, and when the demand shall be for more of these accommodations.

Intercourse between the engineers of this country has *now* become a

necessity. They cannot, as formerly, carry on their works without a knowledge of the progress which has been made in the profession.

The world itself has become too well educated to tolerate for long the charlatan, and it soon strips the lion's hide from the ass.

The great discoveries which are almost daily made in other branches of knowledge, and their application to the purposes of the engineer; the trials of new materials, machines, and methods, and of new applications of old ones; the rapid dissemination of these applications over the civilized world, by telegraph, newspapers, and books, but especially by intercourse, *now* leaves the engineer no excuse for neglecting the most suitable materials, machines, and methods for accomplishing the results demanded of him.

The modern engineer who neglects *any* of these aids, may rest assured that sooner or later *he* will be shelved, and his place supplied by one of those who by closer study and better acquaintance with modern developments, is entitled to the position.

And this demonstrates *one* of the advantages which our institution offers to those engaged in working practically the great problems of the day.

*Here* they can meet others engaged either in the same or a kindred line of labor or thought, with whom they may interchange experiences and reflections. *Here* they can learn all that is published in regard to anything useful in their particular pursuit, and thereby not only avoid past errors, but achieve new results from advanced standpoints, which will secure to them fame and profit.

My engagements lead me to more intercourse with engineers of the interior than many of you, and I can therefore speak of the feelings and interests of that class whom Mr. Kirkwood has so pertinently referred to as necessary to the success of our Society.

When I meet these gentlemen and advocate the Society, I am asked, "What benefits do you propose to confer upon *us!* We can readily see that the Society may be made very interesting and useful to the city members, but what good shall *we* receive from association with them?"

Of course I can show them a good many advantages which will enure to them by becoming members; but I think that we can do more than we have hitherto done, and with a little effort we can offer them more equivalents for their contributions of papers and money; and if

we do this, we shall secure exactly what our Society in its infancy most needs, viz.:

1. To make its advantages more generally known to the profession and to the public, and thereby obtain for it a higher standing and more influence with both.

2. To acquire more members from that class of practical engineers who are daily demonstrating the same problems which the student and man of leisure is examining theoretically.

3. To maintain the financial success of the Society and render it really self-sustaining, instead of taxing unequally a small number of its earnest supporters.

I have found it *necessary* to explain, that the actual existence of the Society has heretofore, and must hereafter depend mainly upon the zealous interest of the resident members, and that the hard work *must* be done by them, or it will not be done at all, and the Society will again die out.

It is proper and necessary that the managers should be selected from the workers, and from this cause the officers have been chosen from among the city members, and I have felt it my duty to make known how much the Society is indebted to them for contributions of what is of much more value than money, viz., their time and their thoughts.

When we shall have become stronger as an institution I shall propose, as a condition of membership, that the candidate shall offer a thesis on some professional subject; and I am not certain but that we ought also to require from each member the annual contribution of a paper, description or drawing of some work of interest.

I fear that our experienced engineers, especially those of the old school, become indolent in recording their operations as they grow older.

If we had among our archives the records of a tithe of the experience of these engineers, it would render our Society so attractive, that we would secure as members almost every practicing engineer in the country.

Among other means of securing more interest on the part of the members from other cities and the interior, I would suggest an amendment of the constitution which would allow those residing beyond the metropolitan district to vote by letter for the officers at the annual elections.

I am aware that this is not in accordance with the practice of other societies, the main objection being that an absent member has no opportunity of comparing opinions on the qualifications of the candidates with the other members, and therefore has to rely wholly on his own judgment, and may sometimes be led to vote on the *ex parte* representations of an ambitious but unqualified member.

If the elections are made by personal voting, it is necessarily confined to a very small proportion of the members, of whom the residents will generally be a majority, and thus the selection will be made by a few persons only.

The local members must, in any event, wield an influential and probably controlling power over the management, and they can, at almost any meeting, mould and direct the *measures* of the Society, so that if an unfortunate selection of officers should at any time be made, they can control the executive as completely as we have lately witnessed in our national affairs.

If the country members are allowed to vote by letter it will increase their interest in the Society, and they will feel that they have an equal share in its management and responsibilities.

It is doubtful whether they will frequently avail of the privilege, but they will probably be better contented with the selections made, by having a voice which they can use whenever they deem proper.

The plans which have been agreed upon for the establishment of a permanent publication fund are of the utmost importance, and I feel great confidence that they will be successful. If we succeed in establishing our Society on a firm basis there is no doubt of the success of the plan.

The committee which has this matter in hand, has prepared a report which will soon be placed before the members. I allude to this subject to enable me to urge upon every one of our members to make it his special duty to aid in carrying out this plan.

The benefits and advantages of our Society to the Engineers of the United States, have been the subject of our worthy late President's address, to which I beg to recall your attention.

There is no profession which as not a similar association of its members, and until we have established our Society upon a stable basis, we shall not be regarded by the public as having really attained a professional character.

Those engineers who by long study and practice are entitled to rank themselves in the profession, have had but little advantage over those who have assumed the name of engineers without much of either, because there has been no standard by which the public could judge of their qualifications.

We all know that the profession has suffered seriously in the public estimation by confounding the former with the latter, and applying to us, as a class, the criticisms which are justly made upon the conduct and works of those whom *we* cannot recognize as engineers.

It will not be long before this institution will become strong enough to warrant the requirement of a standard of attainment for candidates for membership, and more than a mere money contribution to maintain it.

For the present, however, we must be content with our present safeguards against the admission of those who are not entitled to rank as engineers.

With this progress our Society will manifest a power which will be acknowledged, and the public will then deem it unsafe to entrust the conduct of important public works to those who are not members, and our Society, without making itself offensive, will indicate who are, and to some extent, who are not entitled to professional employment.

I cannot better illustrate the benefits and advantages which our Society is capable of conferring upon its members, than by referring to those of the same character in Europe, and especially to that of London, where the people and circumstances most resemble our own.

The London Institution of Engineers consists of more than a thousand of the profession in Great Britain, and embraces what may almost be said to be, the entire body, for there are but few of any standing in the kingdom or its colonies, who are not members, and those few, have in most cases some personal reasons for non-membership.

It is well known that hardly any important public work is undertaken, which has not secured the approbation of this Society, or at least of a considerable number of its leading members.

Even Parliament defers to its decisions to a considerable extent, and the institution which holds weekly meetings during the legislative sessions, is frequently alluded to as "The Parliament of Engineers."

The members are expected to furnish papers on professional subjects, which are examined by the council, and those of most interest are noticed for reading and discussion by the Society ; the discussions often

being of more interest than the papers. Both are published and supplied to members only ; they cannot be procured by purchase except by members.

For four months I attended every meeting of the institution, and never, in the same length of time, derived so much valuable information.

The discussions were carried on by those who were best acquainted with the subject presented, and also frequently by the junior members.

It was a rare treat to listen to the experiences of the veteran Vignoles, the opinions of Barlow, Fowler, Gregory, Cubitt, Russell, Hawkshaw, Whitworth, Hemans, and Bateman, and a hundred more of the eminent men of the profession.

Every subject presented, was most thoroughly discussed, and the concentrated opinions and judgment of these great men was had upon the most important topics of engineering.

The annual volumes of the minutes of this Society, as may be supposed, form almost of themselves a library for an engineer.

The history of this Society should give us great encouragement. In 1771 Smeaton and a few others organized a club of engineers who met at a tavern. Twenty years later it consisted of nearly seventy members, but only fifteen of these were engineers ; among these were Mylne, Jessop, Whitworth, Boulton, Rennie, and Watt.

An unfortunate personal difficulty between one of the members and Mr. Smeaton broke up the Society, but it was reorganized a year later, and still exists under the name of the "Smeatonian Society." Eighteen months ago I attended the annual dinner, and met several of the lineal descendants of the original members, and observed that they still continued the custom of marking their regard to its founder by a toast to the memory of Smeaton.

The present Institution of Civil Engineers was an outgrowth from this Society, and was established in 1818, and incorporated by Royal Charter in 1828. Fourteen years afterwards they had five hundred and twenty-five members, and now number over fourteen hundred.

In 1867 they had as follows :

| | |
|---|---|
| Honorary members | 20 |
| Members | 541 |
| Associates | 771 |
| Graduates | 7—1,339. |

The annual receipts were, £6,300.

And the expenditures, £7,254.

With several funds amounting to £26,709, of which £11,155 was a trust fund, the interest of which in part was expended for the annual premiums awarded in medals, such as the Telford, Watt, Manby, etc., for the best papers.

The annual cost of publishing the minutes of the proceedings of the Society is about £1,800.

There have been similar societies of engineers established in France, Belgium, and Prussia. Those in the other European countries are either semi-military academies or societies under the control of the Government.

The profession to which we belong flourishes best where civilization is most complete. It may almost be considered as one of the luxuries which refinement converts into a necessity.

The comparatively small respect which, at an earlier day, was paid to its members, was due as much to the ruder condition of society as to the want of culture and experience on the part of the engineers.

Civilization is accompanied by a division of labor, which results in the attainment of greater perfection in each line, than if each individual was devoted to several pursuits.

Engineering in Rome, Egypt, India, and even in China, reached its highest eminence during the periods when those nations had, each respectively, attained their highest degree of enlightenment, and though they exhibited works of great magnitude, the conception of great minds and executed with great skill, yet those of modern engineers far surpass them in all these particulars.

The canals of Egypt, India and China, are far exceeded in conception, magnitude, and execution, by the modern ones of Europe and America.

The great military roads which radiated from Rome to the extremity of her empire, dwindle into comparative insignificance with the modern railways, which cover the civilized portion of the globe, and those crossing the Alps and the Rocky Mountains.

None of the ancient bridges will compare with the Menai, Niagara, and a hundred others, and the largest galleys would be but yawl boats for the Great Eastern.

The most eminent of the ancient engineers never conceived of an Atlantic Telegraph, or the application of steam to water and land propulsion, or to the movement of machinery.

But most of all is modern engineering exhibited in the workshops, filled with ponderous machines, capable of turning out masses and form of wrought metal that now give the engineer almost unlimited power over the forces of nature.

A century ago, our country then so recently settled, almost belonged to the ruder conditions of society, and there was hardly any call for the services of the engineer.

During this century society here has advanced with a stride unparalleled in the history of the world; and with it has been the demand for the science, skill and talent of the engineer, to such an extent that it has brought it up from a trade to the dignity of one of the liberal professions.

Even one-half of a century ago, the most eminent of our engineers were chiefly those who had been recruited from other professions or trades, to whom the modern applications of science were almost unknown.

We have passed through a period, when practical knowledge and long experience have been to some degree ignored in favor of theoretic scientific knowledge, and at last reached a period when both are demanded.

During these changes in society, engineering works did not keep pace with the progress made in other matters, and we are now just beginning to replace the earlier rude works, and this labor calls for even more talent than it would have required to originally construct them in the finished manner of the present time.

The progress of civilization and refinement in our country will hereafter be as rapid as it has been during the present century, and the engineer will be more and more called upon to conceive, design, and execute works commensurate with the advancing ideas of the age.

The engineers who are to take our places must combine the highest degree of knowledge with the greatest skill and experience.

We of the older school have fought a long and severe battle to bring the profession up to its present position. The rising school must continue the contest with the same earnestness to maintain its rank with the other professions.

Of an earnest and sanguine temperament, I cannot doubt but that our Society will be the means of accomplishing much toward this end, and that it will become as important and influential as that of London. I

am too old to hope to see the day when our Society will rank equally with those of Europe, but our younger members will, I am confident, witness it.

Meanwhile we must all do our share of the work necessary to accomplish this result ; and if those to whom I have already alluded will continue their earnest and zealous efforts, combined with similar exertions on the part of the other members, it will *immediately* give our Society a position which will make every one of us proud of the title of a

"Member of the American Society of Engineers."

VII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## An Account of the Method adopted to Repair a Breach in the Earthen Dam of the Storing Reservoir of the New Bedford Waterworks. By WILLIAM J. McALPINE, Member of the Society.

"WE LEARN MORE FROM OUR FAILURES, THAN FROM OUR SUCCESSES."

In the autumn of 1866 an earthen dam was built across a small valley near the head of the Acushnet river, to form the storing reservoir of the New Bedford Waterworks.

The dam was six hundred feet long, twenty-five high, twenty feet wide on top, with slopes on each side of two to one.

The left bank of the valley was thirty feet above the level of the swamp, and a table extended eastward for half a mile at nearly the same level. The right bank rose to a level of fifty feet, and extended westward over an irregular but higher district of land.

The earth about the dam, and for many miles in every direction, is the decomposed primary rocks, similar to that of the general coast range, being coarse and fine gravel and sand, with a little vegetable loam on the surface, and with no clay or almost none. Large beds of exceedingly fine sand (chiefly micacious) are frequently found, and occasionally beds of hard pan composed of fine gravel, sand, and loam compacted by pressure.

The banks of the valley were of coarse and fine gravel and sand, and the material in its natural position was somewhat porous and pervious to water, but when removed and carefully selected and placed in an artificial bank of considerable size was perfectly water-tight.

The dam was built in the middle of a heavy wooded swamp. The surface was muck for a depth of two to six feet, and in one place (an old river channel) the muck extended to a depth of twelve feet.

Below the muck was a stratum of hard pan of irregular thickness from one to three feet, and beneath this was a bed of fine sand, which by subsidence and pressure was so hard as often to require to be picked before it could be removed with the shovel.

The soundings showed an irregular surface of rock at a depth of twenty to thirty feet.

At the west end of the dam the stratum of hard pan disappeared, and the sand rose up in the right bank of the valley to a level of twelve feet higher than in the swamp.

The earthen dam was exceedingly well built. There was a puddle wall of ample width in the middle, which was extended in all cases to the hard pan, and generally four to six feet below it, with a "toothed" bottom. The muck under the upper slope of the dam was removed to the hard pan, and in some cases the muck was also removed from beneath the lower slope.

The ends of the dam were pretty well secured by extending the puddle wall well into the natural banks of the valley.

The puddle wall was made of the best materials that could be procured in the neighborhood, which was fine gravel, mixed with coarse and fine sand, and the loamy sand from the surface, all of which were incorporated together by the free use of a large quantity of water and by cutting with spades.

The upper half of the bank was made of the same materials carted on in layers of six inches and kept moist.

The upper slope of the dam was protected by a well-made slope wall of very large-sized quarry stone. The top of the dam was carried four feet higher than top water level in the reservoir. A waste of forty feet length was built at the east end of the dam, which it was considered would prevent the water on the reservoir, even under the most extraor-

dinary rain fall, and circumstances, from rising more than one foot higher than the ordinary top water level.

The reservoir or lake when full, covered about two hundred acres, and the water was twenty feet deep at the dam.

The gate house and waste culvert were made of stone, and the conduit of brick, all laid in excellent hydraulic mortar. The gate house was built at the western end of the dam and was placed at the foot of the upper slope of the bank, and the waste culvert and conduit were extended from it entirely through the earthen dam. The foundations of the gate house and culvert were placed at the level of the lowest water in the river, which was about three feet lower than the surface of the swamp.

The foundation was made by placing on the hard compact sand, a floor of large unhewn blocks of granite, with the edges and end joints hammered off to lines. The stones were laid on a bed of hydraulic cement mortar, and great care was taken to fill the vertical joints tight. The waste culvert was in the form of a segment of a circle of eight feet chord, and three feet versed sine. The conduit was an oval of three and four feet diameters, made by three courses of brick. Its grade was five feet higher than that of the culvert, and it was supported on top of the latter from the gate house to near the middle of the bank, and then was curved to the right and was supported through the lower half of the embankment on a puddle wall.

The lake was filled with water during the early summer of 1867, and remained full until February, 1868. The dam and the waste culvert were frequently examined during this period of six months. The dam itself was perfectly tight.

There was an inconsiderable quantity of water showing itself at the foot of the bank at the east end, but it evidently came from the hill, and perhaps escaped from the lake around the end of the dam. It ran for months, perfectly clear, and discharged less than half a gallon a minute.

A very small stream of water escaped at the lower end of the waste culvert, but this ran clear, and evidently came from the hill side. The workmen drank it, because of its purity and low temperature. The water in the lake at that time was highly colored, and at a comparatively high temperature. There were a few very small holes in the bottom stone and in the arch, where very cold clear water escaped almost in drops.

The author first visited the work in June, 1867. The lake had not then

been filled, but the water in the river had been shut back so as to be at a level five or six feet higher than the bottom of the gate well. A leak had occurred through its foundation (the stone pavement), which had brought up with the water, considerable fine sand. A new floor was then being laid on the inside of the well, which completely stopped the leak at that place. He carefully examined the dam and found that it was perfectly tight, and the only leaks of any kind were the inconsiderable ones already mentioned, which he believed did not come from the lake, and which were running clear and doing no harm. He had the lake filled to a depth of eight feet, and found that it did not increase the quantity of water escaping at any one of these small leaks.

Soon after this date the gates were closed and the lake began to fill. When to its full height, a farmer complained that the water from the lake escaped through the natural soil on the eastern bank, and filled his cellar a thousand feet distant from the lake. The level showed that this water in the cellar was one and a half feet lower than that of the lake.

The author believes that the filling of the lake produced the rise of water in the cellar by shutting up the former subterranean passages of the rain water from the water shed, which discharged into the valley of the river until the water was raised in the lake, and then shut off from this outlet, had to rise in the ground high enough to force its way through new passages into the valley below the dam, and thus flooded the cellar. The matter is mentioned chiefly to show the porous character of the natural soil about the dam.

About the middle of February, 1868, there occurred an exceedingly heavy fall of rain, and as there had been two months of previous heavy rains, and the ground was then frozen, the engineer apprehended that the water might rise too high in the lake.

He therefore raised one of the gates at the gate house, giving an opening of six square feet under twenty feet head. Three days later he sent an intelligent man to close this gate. This person asserts positively that he shut the gate, but he adds that the water continued to flow out through the waste culvert in undiminished quantity, and it is therefore certain either that the rod attached to the gate was broken from it, and thus the gate was not closed, or that the leak in the gate well of the previous June had made a passage under the gate house, and had forced upward some of the pavement stones of the waste culvert.

Several intelligent persons were at the dam within one day of the time that the breach occurred, and did not observe anything wrong. There was no person that witnessed the breach, which occurred forty-eight hours after the gate was supposed to have been closed.

The breach swept out one hundred feet in length of the embankment, and discharged probably within a few hours three hundred millions of gallons of water. Fortunately the dense cedar forest which extended for half a mile below the dam, so much obstructed the flow of this large body of water as to prevent much damage on the river below.

The rush of water at the dam undermined the waste culvert and lowered the pavement two or three feet, and also toppled over the gate chamber.

The author visited the work the middle of May to determine upon the plans for the repairs of the dam and works.

It was very important to discover, if possible, the causes which had produced the breach, but a sufficient number of facts had not been ascertained to determine these causes definitely, and it therefore became necessary to review all of those which *might* have produced the accident :

1. The stone pavement had been placed on a bed of quicksand, which although very hard and compact when dry and undisturbed, became a semi-fluid when saturated and subjected to disturbance. It was as well bedded in hydraulic cement mortar, and the joints filled as close as possible, but it was practically impossible to make these joints all perfectly tight, and many of the openings between the stones in places were of considerable width.

The discharge water passing through the culvert had a velocity of ten feet per second, which was sufficient to force its way downward into any imperfect joint, and to rapidly wear away any portion of imperfect mortar until it reached the very fine sand on which the pavement rested; and this would be quickly removed by such a current of water, and cause one or more of the stones to settle, and then the current would rapidly extend its efforts under other stones, and soon cause the culvert to settle and break and leave the lake water free egress through the embankment.

That the pavement had some such imperfect joints was shown by the leak which had occurred in June previously, and that the pavement was undermined as above hypothetically stated, by finding the stones at a

level two or three feet lower than that at which they were originally laid.

2. The segment form of the waste culvert arch produced a horizontal thrust upon the stones forming the foundation.

These stones did not extend entirely across the foundation (transversely). That is, from three to four stones were used to make up the width of twelve feet. This thrust was produced by the weight of the stone arch and of a body of earth, which, in moist condition, would bring a weight of forty tons per lineal foot on the arch, and to resist it was only the inertia of half a ton, the friction on the earth, and the resistance to the compression of moist or wet earth of less than two square feet area.

These single stones may, therefore, have been forced into the earth horizontally, and thus joints opened to the attack of the current of water, or the arch stone may have slid upon the pavement, and in either case allowed the arch to fall and thus open a passage for the lake water through the embankment.

3. The conduit had an unequal support in passing through the embankment. From the gate house to the middle it was firmly supported upon the stone waste culvert, and for the lower half less firmly upon a puddle wall. Under the pressure of the superincumbent weight of earth, the conduit would force itself into the moist puddle, and thus by an unequal settlement, crack its masonry at or near the place where it lost the support of the culvert masonry.

The heavy rains and the filling up of the waste ditch had backed the water from the swamp below, so as to nearly close the mouth of the waste culvert. When the gate was raised, the water in the well probably rose high enough to allow a considerable stream to pass down the conduit. When this water reached the crack or break in its masonry (which has been *assumed* to have been made near the middle of the embankment), it flowed into the embankment (which in this place had been made of fine sand), and soon carried off the lower half and eventually the upper half of the bank.

4. The water from the lake under twenty feet head might have forced a small passage through the fine sand entirely below the base of the dam and of the foundation of the masonry, and gradually enlarging itself have finally produced the breach.

A consideration of all of the circumstances of the case led to the belief that the breach was caused by the first of the conditions above named, and that it was probably aided by the second.

Nevertheless, it was regarded as prudent to provide in the new work as far as possible, against *all* of the causes which might have produced the disaster.

The plans which were determined for the repairs were as follows:

1. To remove the quicksand across the breach, for the whole width of the base of the dam, as low as could be done without great expense, and replace it with fine gravel, mixed with a little loam (which was the best material which could be procured without hauling a dozen miles).

2. To place the waste culvert at a level three feet higher than in the original structure, so as to have its foundation resting on the greatest possible depth of gravel, and to build the culvert and conduit as one piece of masonry entirely through the bank.

3. To place the gate house about forty feet above the upper toe of the dam, and extend a bank of gravel to cover the culvert and conduit from contact with the water in the lake.

4. To *place* within the main bank two rows of water-tight sheet-piling, which should extend as deep as possible into the quicksand below, and at least twenty feet horizontally into the old bank to the east of the breach, and at least as far into the side hill at the west, and to make a gravel puddle wall between these rows of piling, sunk as deep and as far into the banks at the ends as practicable.

5. To remove the slope wall from the face of the old bank and from the hill side for at least sixty feet horizontally, and face the bank anew with gravel of three feet thickness at top and six feet at bottom (at right angles to the slope).

To foot this facing at least four feet deep into the swamp, and in all cases to the stratum of hard pan, to which it should be carefully connected, and to uncover this stratum of hard pan for a circuit of one hundred feet radius above the toe of the dam, examine its depth and make it (by adding gravel) a perfect lining over the whole bottom, and at its up-

per extremity to connect it with a cut-off of gravel sunk four feet deep into the underlying stratum of quicksand.

These precautions may at first thought seem to have been further extended than the case warranted, but a personal examination would soon convince an experienced engineer that it was really one of the worst cases that he is often required to meet.

The disturbance in the bed of quicksand, caused by the breach and by the ordinary operations of the repairs, had changed it from a material of hard consistence to a semi-fluid, which flowed in from all directions and left the whole of the earth about the work porous or perhaps cavernous.

This sand, which seemed to be so compact, was really very pervious to water. In the pump pit the water came in from all directions, as well from below as from the sides, at a level many feet below the surface.

The quicksand, which was overlaid by hard pan through the swamp, and was elsewhere from four to six feet below the surface, rose to a level of twelve or more feet higher in the west bank, and the covering of hard pan had disappeared at this end of the dam; and finally the deficiency of information in regard to the causes of the breach, left on the mind that degree of uncertainty that naturally induced to the taking of more than ordinary care to prevent a repetition of the disaster.

The chief object of care was to place the sheet-piling at the lowest possible depth, and to make it perfectly water-tight against a head of more than twenty feet.

Engineers often use sheet-piling by driving single planks or timbers, sometimes with tongues inserted and sometimes with a double course breaking or covering the joints.

The author holds the opinion that in most cases such sheet-piling is not only useless, but is positively detrimental, and for a great many years he has used none but *placed* sheet-piling; that is, by excavating a trench to the requisite (or greatest practicable) depth, and placing in the bottom a timber, to which closely jointed plank are spiked (being also spiked to a similar timber at the top), and covered by a second course of jointed boards or plank. In other words, making a barrier perfectly water-tight against the head of water which will be brought against it.

When the plank are thus placed, the trench is filled with fine gravel mixed with a little loam.

It is impossible to drive plank singly and make a water-tight joint. The tongues or coverings are generally useless.

To prove this, let the greatest care be taken in driving some plank in a dry place. Then remove the earth and you will find the bottom joints of the piling open in both directions: and if tongues have been used, many of them will be found to have been split off at the bottom and useless, and no covering plank can be put on, much less driven, which will make the joints water-tight.

Such sheet-piling will not resist one foot head of water; and if water will pass through, then will the fine sand and loam or clay, and the whole piling becomes not only useless but deceiving to the engineer who has relied upon it; and who may from that cause lose his structure.

But this is not all of the danger to be apprehended. Water will follow along a smooth surface for a great distance (horizontally and vertically), until it finds these open joints, through which it will freely pass, and then upon the opposite side, where it will continue to search for some escape under or around the structure.

Water abhors angles, and by compelling it to make a sufficient number, its head can be entirely destroyed and prevent any damage.

The author desires to call the attention of young engineers especially to this point.

The interposition of these angles is often the only weapon of defence that the engineer can avail of, against his worst enemy, and most useful ally—water.

In placed sheet-piling you can provide at the bottom as many of these right angles as you deem necessary by means of the plank and timbers, which will generally give you seven angles, and these may be increased to any desired number.

Many young engineers fill their piling trenches with clay puddle.

The author greatly prefers fine gravel, with a little loam mixed with it.

The first coffer dam at the United States dry dock gave way, chiefly because it was filled with clay. The one built by the author withstood a greater pressure because it was filled with gravel.

Even paving stones were allowed to be put in the coffer dam, where they were surrounded by gravel.

The particles of clay are cohesive, and a vein of water ever so small

which finds a passage under or through clay is continually wearing a larger opening.

The particles of fine gravel, on the other hand, have no cohesion.

Such a vein of water as has been mentioned, first washes out from the gravel the fine particles of sand, and the larger particles fall into the space, and these small stones first intercept the coarser sand and next the particles of loam, which are drifted in by the current of water, and thus the whole mass puddles itself better than the engineer could do with his own hands.

The vacuities produced below, by this operation, are indicated by the settlement at the top, where more gravel, etc., can be added as is found necessary.

An embankment of gravel is comparatively safe, and becomes tighter every day.

One of clay is much tighter at first, but is always liable to breakage, from the causes already mentioned.

For the same reasons the piling trench should be filled with gravel, so that if any vein of water escapes through or below the sheet-piling, the weight of the gravel will crush down and fill up the vein, before it can enlarge itself enough to produce danger.

A matter of great importance was to get the sheet-piling placed as deep as possible.

The author hoped to succeed in placing it ten feet deeper than the old foundation, which would have brought it to within five or ten feet of the rock.

It was of course considered that if the piling was extended to the rock it would be much safer, and it would have been easy to have *driven* sheet-piling down to the rock; but for the reasons before stated this would have been seriously objectionable, because we could not hope to make the piling water-tight, nor to make a water-tight connection with the irregular surface of the rock, and the pile plank would have conducted the water more freely through the quicksand, where it would have more readily escaped along the surface of the rock, than through the sand itself.

A mill dam, three-fourths of a mile above the work in question, had been raised and repaired, and arrangements were made to retain a great body of the water which flowed down the river, while the more difficult

part of the operation was in progress; but the excessive rains which prevailed during the season, prevented the use of this aid to the operations.*

A wooden sluice was built around a part of the piling pits, but the semi-liquid quicksand assumed such flat slopes, that the sluice was found to be too short at each end to carry the water of the stream past the whole length of the pits, and it had to be conveyed to and from the sluice by open canals.

A steam engine of nominally ten-horse power and a pump were provided, for the purpose of raising the water and sand.

This pump delivered forty cubic feet of water per minute, when lifting it thirteen feet high.

The power applied was five and a half times the effect produced, which covered the friction of the machinery, increased greatly by the sand, and the loss of the water by loose buckets.

The power of the engine was exhausted by the time the depth of twelve feet was reached.

The problem now before us was one of considerable difficulty. The sounding rods showed that the material to a depth of from twenty to twenty-five feet, was of the same character as that at and above the level of the river, viz.: a very fine sand, in fact a very troublesome quicksand. It was necessary to excavate a piling-trench in this semi-fluid to a depth of at least fifteen feet.

On the one side we had the river flowing through a wooden sluice and canals, and a heavy embankment of twenty-five feet height pressing down upon the bed of quicksand adjacent to the pit. On the other side was a steep side hill of fifty feet height pressing down upon a similar bed of quicksand.

The excessive rains had filled the swamp and lands adjacent to the pit with water, to their utmost point of saturation. This quicksand was very pervious to water, and hence a large quantity of water might be anticipated to come into the pit during the operation, and if the work was protracted, the high banks on each side would be undermined and cave into the pit.

* The rain fall from the 1st of January to the 1st of June (five months) was thirty-six inches, the average *annual* rain fall in that section being forty-two inches.

There are three rules to be observed in excavating quicksand, and they are here stated concisely so as to impress the reader:

1. The water must be removed promptly and thoroughly.
2. The excavation must be made with the utmost despatch.
3. The material must not be disturbed after it begins to quake.

Now, these rules are almost never observed. It is almost impossible to make either engineers, firemen, or workmen follow them, and hence arise the chief difficulties and expense of removing quicksand.

If they are strictly followed, the author guarantees that the difficulties and expense will be reduced one-half at least.

Quicksand is defined to be a mixture of fine sand, with such a proportion of clay or loam as enables the mass to retain water within itself; and when in this condition, after it has been trampled upon for a short time, it begins to quake, so that it may also be called "quakesand." When it reaches this condition, if it is left quiescent for a few hours, the heavier particles of sand and clay settle down and expel the water, and the mass becomes again firm. If, on the other hand, it is further disturbed by the feet of the workmen, it becomes more and more fluid, additional material flows in from the sides, and no progress can be made in the excavation.

When the engineer has such a work in hand he should provide an ample pumping power. And here it may be noted that in most cases he will find that a power even five times as great as he anticipated will often in the end prove most economical.

The pumps should be capable of lifting sand as well as water, and those are best which are not liable to be clogged. This is of more consequence than that they should work with a good "duty."

The author has found that in most cases sheet-piling protections around the pit to prevent the influx of sand are useless and often detrimental. If there is room to allow the excavation to take its natural slope, and the three rules are observed, the sheet-piling protection will be found unnecessary. Quicksand in a dry state may be excavated nearly vertical.

These views will be illustrated by describing the operations at the place in question.

The pit was commenced on top about fifty feet wide and one hundred feet long.

There were thirty laborers employed, who were arranged as follows: Six were kept constantly employed in removing and casting aside the sand from about and under the pump, to keep it far below the other parts of the excavation; twelve men were constantly employed in opening small ditches radiating out from the pump pit; six men were employed in excavating the ridges left between the radiating ditches, and as long as the latter were kept open these ridges offered perfectly dry digging.

The remainder of the men were employed in casting further back the earth which was thrown out by the six men last mentioned.

It will be seen that the actual removal of the earth was measured by that done by only six men out of thirty, but these men had perfectly dry work.

It was with considerable difficulty that the workmen could be forced to follow the three rules. They were constantly violating them, although they constantly had palpable evidence before them of the efficacy of the rules and the disastrous results as soon as they were neglected. On visiting the work ten days afterwards the author observed that they had almost forgotten them.

All things being in readiness, the work of excavating was commenced early in the morning, and by mid-day the pit had been sunk in the lowest place to a depth of twelve feet, and then it appeared that the extreme power of the steam engine to remove the water had been reached, and it soon became impossible to keep open the radiating ditches, and consequently the earth between them became suffused, and soon after the whole of the lower portion was transformed from hard compact sand to a mass of semi-fluid material, quaking like jelly. The water began to "boil up" in many places in the bottom, and it was evident that no further progress in the excavation could at this time be made.

The author's time did not permit him to remain for another trial on another day, and therefore he changed his plans as follows:

It was considered very important that the sheet-piling should be placed at a much greater depth than that to which the excavation had now been carried. To *drive* the plank to the desired depth, as has already been mentioned, would have resulted in open joints at the bottom. It was therefore determined to lessen the *number* of such joints by making up the plank in panels of four feet width, with its joints matched and battened with one inch boards.

One of these panels was placed in the proper line of the sheet-piling, and forced down by *pressure* nearly five feet deep.

The non-fluid condition of the sand permitting this penetration, a second panel was forced down in the same manner, and with considerable trouble a tolerably close joint was made with the first panel, and further secured by a plank which was driven over the joint.

In this manner successive panels were put in, until the whole width of the pit was covered by two rows of sheet-piling placed fifteen feet apart.

It will not fail to be noted, that the joints between the panels thus placed, must of necessity be nearly as open as in any other driven sheet-piling, and that this plan did not, therefore, accomplish the result aimed at. For it will be remembered, that *any* water reaching *any* part of the sheet-piling, would flow horizontally until it reaches one or more of these open joints, through which it and fine sand would escape, and thus render the sheet-piling nearly or quite useless.

But it had already been determined to obtain a more powerful engine, and with its aid to remove the water, and then the earth from *between* the rows of piling to the same depth to which they had been forced, and then to batten and caulk up the joints between the panels on the inside.

While the question of the necessary power of the new engine was being discussed, it became desirable to ascertain how much of the water which flowed into the pit, came from the leaky sluice and the canals, and how much of it came from the natural water courses through the sand.

The material being of so porous a character, it was impossible to determine this question merely from the directions in which these small streams came, and at first thought it seemed impossible to arrive at any definite or reliable conclusion in regard to the comparative quantity from each of these sources.

He happened to have his pocket thermometer with him, and with it obtained the temperature of the water flowing through the sluice-way and canal. The temperature of each of the small streams and springs flowing into the pit from the various quarters, was then taken.

The result was surprising.

The temperature of the water in the sluice was 74°, and that of one set of the streams ranged from 71° to 73°, and of another set was from 56° to 61°, several of them flowing but a few feet from each other, with these widely differing temperatures.

Those of the higher degrees were evidently the leakages from the sluice-way and canal, and those of the lower temperatures as evidently from deep-seated springs.

The average mean temperature of the air for the year was 51°, and consequently the water issuing from deep-seated springs, would have been as low as 51°, if it could have been intercepted and tested before it was increased by contact with the atmosphere, which at this time was about 82°.

A rough, but sufficiently accurate gauge of each of the twenty small streams was made, from which it was ascertained that two-thirds of the water which came into the pit was leakage, the greater part of which could be prevented by a new sluice, and a better connection at the ends.

The new sluice would cost less than two hundred dollars, and a new engine more than two thousand dollars.

With a diminution of more than one-half of the quantity of inflowing water, the engine on hand would be of ample power to free the work from water, and enable us to get down to the requisite depth, and caulk the joints of the sheet-piling, and put in the puddle.

This simple expedient, therefore, saved an expenditure of nearly two thousand dollars.

The masonry of the gate house, culvert, and conduit, is all laid in hydraulic cement mortar.

It rests upon a foundation of timber, and two courses of plank.

Concrete masonry is filled between the timbers, to take their place if they should ever decay, which, as they will always be submerged, will not soon occur.

There was another source of danger which had to be guarded against, viz., that the water would follow along the sides, top, or bottom of the masonry, through the whole width of the bank, and escaping at the lower side, again produce a break.

To prevent this, belt walls of masonry were built at each row of sheet-piling, and one still further toward the gate house. These belt walls extend three feet beyond the outside lines of the masonry of the culvert and conduit on the bottom, on the side, and over the top, and are built up with the other masonry, thus forming a perfect cut-off to the water at each belt. The outer faces of these belts are "toothed," to produce angular obstructions to the water.

It will naturally be asked, why was not the piling and puddle across

the breach extended down to the rock, and thus cut off the passage of the water through the quicksand below with certainty?

The reply is, that it would have been attended with an enormous expense, and was not believed to be necessary.

It had been demonstrated that the remainder of the dam, for a distance of six hundred feet resting on the same bed of quicksand, was perfectly tight.

The weight of thirty feet in height of gravel had so compressed the sand as to make it impervious to the lake water under twenty feet head.

Across the breach we would have, for the middle portion of the bank, the weight or pressure due to at least ten or twelve feet more height of bank, and the stratum of sand would be of less thickness and at a much deeper level than under the remainder of the dam, and therefore that this portion of the dam would be safer in this respect than that part which had been already found to be sufficient.

Besides, the gravel and hard pan over the bottom would be extended a considerable distance above the foot of the dam, and the water must therefore force its way through the sand so much further than at the other parts of the tried dam, that it was considered more secure from these causes than elsewhere.

The most dangerous places now in the dam are where the repaired work joins the old dam and at the west end against the hill side.

These places are secured by the jutting of the piling and puddling into the old work, and by the lapping of the gravel used in filling the breach a long distance horizontally on the face of the old bank and on that of the hill slope, thus compelling any water coming from that direction to pass around the ends of two water-tight facings, and also for a long horizontal distance between them before it can get below the water-tight portions of the work.

The foregoing account has been written out with more detail and particularity than necessary, for the information of experienced hydraulic engineers.

It is intended chiefly to interest the younger members of the profession, and particularly to enable the author to introduce a few of his practical experiences; such as the best method of excavating quicksand; the use of placed instead of driven sheet-piling: the substitution of gravel for clay to resist the escape of water in dangerous places; and the

method of preventing the passage of water along smooth surfaces by fatiguing it with angles.

On some of these points he is aware that the practice of other engineers of experience differs from his own.

He will be glad if the foregoing remarks elicit some discussions which will lead to the determination of the best practice on these subjects.

If this paper should sufficiently interest the members, the author proposes from time to time to lay before them those of a similar character, to enable him to put on record the practical results of a long service in the profession, for which he has already collected abundant materials.

In preparing this paper he has made no effort at elaborate writing, in the hope that it will induce many young members to submit their experiences to the Society, and thus instruct themselves as well as their associates.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

VIII.

# ARCHING BERGEN TUNNEL ON ERIE RAILROAD.

A paper from JOHN HOUSTON, Civil Engineer, read before the Society, October 7, 1868.

*Dear Sir* :—According to promise, I send with this the details of the centering used by me in the arching of a part of Bergen tunnel, last year. It was constructed so as to allow the free passage of trains during the prosecution of the work, and as the drawings will explain for themselves I now only give you a description of the manner in which the work was done.

The tunnel is cut through trap rock to a certain area; it is twenty-eight feet wide up to the spring of the arch, and twenty-three feet high from its crown to subgrade. The arch has three centres, as shown on the section.

As it was necessary to excavate a large quantity of rock to make room for the brick work, without lessening the original area, this excavation was economized as much as possible, by using a granite springer ten inches thick and about three feet deep, for which a shelf was cut in the rock—the side walls of solid trap being left as they were, wherever the excavation was wide enough to allow room for one thickness of brick, as it was considered that the rock itself was sufficient for the abutments, after being lined with brick, and filled solid with brick and cement in all its irregularities.

During the progress of the work (which was done entirely through the night), all trains were run on a single track. Telegraphic communication was established between the extreme ends of the tunnel, and a regular system adopted to prevent accident to the trains or workmen employed. The excavation was completed on one side at a time at each place where the arching was to be constructed.

The boring and blasting was done on scaffolds, built on flat cars placed on the track ; a locomotive and cars being constantly on hand to remove the rock after it was blown down. On such parts of the track as the rock was likely to fall, it was covered with timbers, to prevent injury to the rails, &c.

After the miners got far enough ahead, the bricklayers went on, and built the side walls and coped them.

The centering was then placed, and the bricklayers continued with the arch, working from scaffolding placed on cars also. The centering was made out of an ordinary 6″ wrought-iron girder. It was bent to the correct form of the tunnel whilst hot, and each rib was made in two pieces, and joined in the middle with a fish plate, from which depended an 1¼ inch (round) iron rod with an eye in the lower end, through which another 1¼ inch (round) iron rod passed across the tunnel, at a height from the rail sufficient to allow the highest locomotives to pass. This rod, as shown in the drawing, was furnished with a turn buckle, to draw the ribs to an exact line. Ten ribs, placed three feet apart from centres, were used braced and tied together, as shown on the side view.

In putting up the iron frame work, one rib was first placed and securely guyed, the bracing was then attached to it, and the next rib then placed and fastened to it, and so on until the whole was connected and ready for the masons. The supports were formed of timber work, as shown on the drawings. The ribs rested in cast-iron shoes fitted on a plate and supported on wedges, a second plate, and cast-iron rollers placed between it and the main supports. The rollers were cast very rough and had holes in the outer end to admit an iron bar to be used as a lever for turning them—the roughness preventing slipping. When a section of the arching was finished, the keys or wedges were knocked out sufficiently to allow the whole frame to drop low enough to allow the wooden sheathing to be drawn, and then an additional length of supports having been placed, the whole was moved forward with levers operating directly on the rollers. When the frame was moved far enough ahead,

the keys were driven so as to elevate it to the proper height, and it was ready for the bricklayers again. After the men employed on the work gathered the necessary experience, they could move the entire section of centering (about twenty-seven feet in length) without delaying the bricklayers more than an hour and a half. The arches built vary from 16 inches to 36 inches in thickness, depending on the weight of loose material they have to carry.

Where they are used as a mere lining they are 16 inches thick ; where a quantity of loose rock has been removed, leaving a space between the brickwork and the solid rock, they are made heavier accordingly ; and under the shafts, which are about 70 feet deep from the crown of the arch to the ground surface, they are 36 inches thick.

In every case the space between the solid rock and brickwork is packed with clean dry stone packing ; this packing was carried up with the brickwork. Four-inch cement pipes are built into the side walls about 10 feet apart, for the purpose of carrying off the water which might collect on the arch.

They are carried up to the spring line, and have their outlets near the grade line of the tunnel.

We arched in the manner described between five and six hundred feet without difficulty or any accident, the greatest obstacles being the intense darkness and dense smoke.

Altogether the work was a perfect success.

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## IX.

## ON THE APPLICATION OF A NEW SYSTEM OF DISTILLATION WITH CONSERVATION OF HEAT.

A paper read before the Society March 3, 1869, by THOMAS PROSSER, member of the Society :

DISTILLATION, in its broadest sense, is the subject of this paper; and I am desirous of obtaining a thorough discussion on the cognate subject of HEAT in connection with *water* and *steam*, but more particularly in regard to its *latent* state.

The Physicists have investigated the subject most laboriously, and to some extent, it must be allowed, successfully; but what has the engineer done in its behalf? Literally nothing. He has been plodding away with his *practical experience*, as he calls it, manipulating the iron, and steel, and brass, like another Tubal-Cain: but of the elementary principles of the *steam* which operates his ENGINES when completed, he has made no inquiry, and we are not quite certain that they have not retrograded since the time of Watt, when "a bushel of wheat ground and dressed in an hour with eight pounds of coal, was one-horse power," but now it requires eleven pounds, according to Mr. Isherwood. As a material, he has weighed and measured it; as a production, he has ascertained its cost; but as a *power*, he has *never* yet attempted, in a rational manner, to economize it. True, he has patented

it, petted it, puffed it, expanded it, superheated it, and called it an infant, and knows that it is a most extravagant one—at least, he believes that it is, for it wastes nine-tenths of its food, as the physicists have told him; but still he follows in the wake of his *predecessors*, shutting his eyes against the only method which leaves much apparent hope of *improvement*—for, surely, where nine-tenths are wasted, there is ample margin for that.

In order that my *main object* may appear at once and conspicuously, I will state briefly, at the outset, the grounds on which I claim your special attention.

Heat, as you are aware, exists in vapor in, *at least*, three—perhaps four or even more—different states, viz., the sensible, the latent, and the specific;* but the latter may be omitted as an unnecessary refinement for our present purpose, the sum of the other two being regarded as constituting the "*total heat.*"

There are also three theories in regard to the proportions in which they exist; but the one universally accepted is that of M. Regnault, whose elaborate experiments were made about twenty-two years ago. Those experiments show that vapor, under the pressure of the atmosphere, has 637† calorics, of which 100° C. only are sensible and 537 latent. The total heat increases, while the latent heat decreases, by addition to the temperature; hence, the high-pressure steam-engine can be worked most economically in proportion to the elastic force of the steam (for the sensible heat alone is effective), although it wastes into the open air the whole of the heat which remains in the steam at the end of the stroke. On the other hand, an ordinary surface-condenser, operating on atmospheric steam down to a temperature of 30° C., washes away to waste 607 calorics with a flood of cold water, being equal to ninety-five per cent. of the whole of its total heat.

Is not a statement like this enough to make one blush for the profession? Although the fact has been palpable for many years, yet, up to the present time, no attempt, that I am aware of, has ever been made to utilize the latent heat in vapor in a comprehensive manner; on the contrary, all that has been done or attempted, has been its destruction.

Here, then, is a field for operation. With a margin of ninety-five per

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* And qy. the expanded state.

† Degrees centigrade.

## TABLE No. 2.

| WATT. | | | | | SOUTHERN AND CREIGHTON. | | | | | REGNAULT. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total. | | Temperature. | | Latent. | Total. | | Temperature. | | Latent. | Total. | | Temperature. | | Latent. |
| Calorics. | | Degrees. C. | | Caloric. | Calorics. | | Degrees. C. | | Calorics. | Calorics. | | Degrees. C. | | Calorics. |
| 606.5 | = | 0 | + | 606.5 | 606.5 | = | 0 | + | 606.5 | 606.5 | = | 0 | + | 606.5 |
| 606.5 | = | 1 | + | 605.5 | 607.5 | = | 1 | + | 606.5 | 606.808 | = | 1 | + | 605.805 |
| 606.5 | = | 2 | + | 604.5 | 508.5 | = | 2 | + | 606.5 | 607.11 | = | 2 | + | 605.11 |
| 606.5 | = | 3 | + | 603.5 | 608.5 | = | 3 | + | 606.5 | 607.415 | = | 3 | + | 604.415 |
| 606.5 | = | 100 | + | 506.5 | 706.5 | = | 100 | + | 606.5 | 637. | = | 100 | + | 537. |
| 1. | = | .16488 | + | .83512 | 1. | = | .14155 | + | .85845 | 1. | = | .15699 | + | .84301 |

cent., surely some salvage is obtainable. In order that there may be no doubt of the existence of this enormous quantity of latent heat, I have placed the three theories (before alluded to) respecting it, in chronological order, calculated, however, on the basis of Regnault's for the total and latent heat, at 0° C.

It appears that Regnault's theory is about a medium between the other two, but in neither case is the difference a material one. According to Regnault, the total heat *increases* .305, while the latent heat *decreases* .695 calorics, for every degree of increase in temperature.

Watt's theory is, that the *total heat* is the same under all circumstances, and, therefore, the gain of temperature equals the loss of latent heat, which is, at least, intelligible, but Regnault's is not.

Nor is this the only difficulty in assigning as of equal value a degree of temperature, and a unit of caloric of latent heat, and mixing them together in the *total heat.*

The Tables (No. 2) commence at zero for temperatures, while the latent heat in Regnault's (and, of course, the total heat also) is represented by 606.5 calorics. The absolute zero must, therefore, be

$$-1988.52459 = \left(\frac{606.5}{.305}\right) \text{ or nearly } -2000^{\circ} \text{ C.},$$

before the "total calorics" are exhausted.

In like manner, there can be no more "latent calorics" above the temperature of $872^{\circ} = \left(\frac{606.5}{.695}\right)$

for $872 \times .305 + 606.5 = 872$,

and $872 \times .695 = 606.5$ (nearly).

Verily this latent heat is a great mystery.

The following Table (No. 1) is supposed to commence at the absolute zero, and continues until the ordinary zero is arrived at: when, presto! it is all changed, in the manner shown by the bottom line, which is the same as the top line of the previous Table:

**TABLE No. 1.**

| TOTAL. | | TEMPERATURE. | | LATENT, |
|---|---|---|---|---|
| Calorics. | | Degrees, C. | | Calorics. |
| 0.0 | = | 0.0 | + | 0.0 |
| .305 | = | 1. | + | — .695 |
| .61 | = | 2. | + | — 1.39 |
| .915 | = | 3. | + | — 2.085 |
| 1.22 | = | 4. | + | 2.78 |
| 1.525 | = | 5. | + | 3.475 |
| 1.83 | = | 6. | + | 4.17 |
| 2.135 | = | 7. | + | — 4.865 |
| 2.44 | = | 9. | + | 5.56 |
| 2.745 | = | 8. | + | — 6.255 |
| 3.05 | = | 10. | + | — 6.95 |
| 30.5 | = | 100. | + | — 69.5 |
| 305. | = | 1 000. | + | — 695. |
| | = | 1 988.52459 | + | — |
| 606.5 | = | 2 000. | + | — 1 393.5 |
| 606.5 | = | 0. | + | 606.5 |

See Table No. 2.

Now, the last line of the Table (No. 1) should be the same as the first one of the previous Table (No. 2); but, instead of that, we find only the first column, or the "total calorics," the same, while from the "temperature" of 2 000 degrees the *whole* is dropped, and from the "latent calorics" 787., with the negative sign, leaving but 606.5

Table No. 3 is an attempt to put Table No. 1 in a more comprehensive form; for which purpose it commences at the absolute zero and continues to the ordinary zero, and thence to the abolition of latent heat, embracing part of a range of 2 872° C.

**TABLE No. 3.**

| TOTAL. | | TEMPERATURE. | | Calorics. |
|---|---|---|---|---|
| Calorics. | | Degrees, C. | | LATENT. |
| * 0.0 | = | — 2 000. | + | 2 000. |
| 301.5 | = | — 1 000. | + | 1 301.5 |
| 576. | = | — 100. | + | 676. |
| 603.45 | = | — 10. | + | 613.45 |
| 606.195 | = | — 1. | + | 607.195 |
| 606.5 | = | 0.0 | + | 606.5 |
| 606.805 | = | 1. | + | 605.805 |
| 872. | = | 872. | + | 0.0 |

* Absolute zero.

The "*total* calorics" at the "absolute zero" is *nothing*, while the "temperature" is (—2 000), or 2 000° C. less, which, somehow, the "latent calorics" appear to have got hold of; and that balances the account, after a fashion which I must confess is totally unintelligible to me.

If the temperature or sensible heat is increased, it may be imagined that the latent heat decreases in the same ratio, leaving the total heat the same as before, and according to Watt's theory. The same may be said of the theory of Southern and Creighton—the latent heat remaining the same, while the total heat increases in the same ratio as the sensible heat. But what shall we say of the latent heat decreasing faster than the total heat increases?—for that is a solecism in physics. Perhaps Dr. Tyndall can explain it, for he makes the absolute zero—273° C. on the same authority (M. Regnault) as I make it nearly —2 000° C.

Because the elastic force of a gas is doubled by an increase of temperature from 0° to 273° C., "it is manifest," says the Doctor, "that, at a temperature of 273° C., we should cease to have any elastic force whatever." Perhaps so; but inasmuch as we are dealing with a phantom hypothesis, let the phantom have a fair chance. In the case of *aqueous vapor*, the cold has annihilated it at —2 000° C., for it cannot be supposed to exist at that temperature. But an uncondensable gas is a wholly different affair, and we can imagine its existence at any temperature, or no temperature at all; but we cannot admit of two absolute zeroes. I would not have ventured upon such a line of argument as this without some high authority, for it assuredly gives the most absurd results imaginable, and shows, to my mind, that we are, even now, ignorant of the exact status of latent heat in steam.

The question of latent heat is sufficiently puzzling. It passes through water without giving any indication of its presence, except that it carries away the water itself in the shape of vapor—a pretty strong proof that there is something *material* about it. And here we encounter the new school of Natural Philosophy, which insists upon the *immateriality* of heat (a term, however, which is never used), which is about as difficult to comprehend as any of the ghostly manifestations, which cast too strong a shadow to allow of the supposition that there is not a substance somewhere near. Surely, then, it is too early for the new school to cry Victory! for "When the old owl winketh, little doth the young owl know what the old owl thinketh." That is to say, there are still some

questions of the old theorists to be answered before the new ones can expect their "glittering generalities" to be accepted as gospel. They are too aggressive, violent, and radical. Moreover, they have urged their claims with but little dignity or courtesy; for, while they have not forgotten the "mutual admiration" proclivities of their class, in calling up their own members for special greeting, they have scarcely thought it worth while to mention any of the great men who have held, and do now hold, to contrary opinions.

Thus, Professor Tyndall dismisses Gmelin with the simple epithet, "laborious," as if he were merely a beast of burden. In his "Heat considered as a mode of Motion" (Am. Ed., Appleton & Co.), at page 38, he says: "The laborious Gmelin, for example, in his 'Hand-Book of Chemistry,' defines heat to be that substance whose entrance into our bodies causes the sensation of warmth, and its egress, the sensation of cold,"* referring by the star to a foot-note, thus, "English edition, vol. 1, page 22." The "English" edition, however, contains no such passage, if the reference is made to the Cavendish one, and I know of no other.

On the same page he says: "He (Gmelin) also speaks of heat combining with bodies, as one ponderable substance combines with another; and many other eminent chemists treat the subject from the same point of view." But what does Gmelin say (Vol. 1, page 160) ?—here are his own words: "The imponderables are: light, heat, electricity, and magnetism."

Again, Tyndall, in a foot-note, page 39, says: "I have particular pleasure in directing the reader's attention to an abstract of 'Count Rumford's Memoir on the Generation of Heat by Friction,' contained in appendix to this lecture. Rumford, in this memoir, annihilates the material theory of heat. Nothing more powerful on the subject has since been written."

Now, as the *memoir* referred to has been before the world more than seventy years, it is not very creditable to the new school that *it* should have remained so long uncanonized; and still more unaccountable is it, that the materialists should not even now know that their idol has been dead since all that time.

On the whole, there appears to be too much of a partisan feeling and too little of the philosopher to command respect; and as to the

"mechanical equivalent of heat," the language applied to it by its author, Dr. Joule, many think, may just as well be continued, from vol. 33 of the "Phil. Mag., London, 1843," page 443—"*The hypothesis is, I confess, sufficiently crude.*"

But, in vol. 35 of the same work, 1849, on the "mechanical equivalent of heat," at page 533, the Doctor had gained sufficient confidence to say, "Heat is not a substance, but a mode of force." But, after all, Webster's Dictionary is the best guide, which says, "This theory of heat seems not to be fully settled." Tyndall (page 39) says that *heat* is "an *accident* or condition of matter: namely, *a motion of its ultimate particles*," which appears to be the same as Joule's "*mode of force.*" But what, then, is "motion" or "mode?"—what produces them?—for it will not surely be pretended that they produce themselves.

THE NEW SYSTEM OF DISTILLATION WITH CONSERVATION OF HEAT.

However *trite* the remark, that "Vapor is of the same *temperature* as the fluid from which it is produced," there is nothing *trite* about the subject-matter itself—*Heat*—or, if the savans allow—*Calorics.*

Still, at the very outset we are baffled in the attempt at generalization, for the fluid must be chemically homogeneous, or the vapor from it will not correspond with the text; for the vapor of sea, or any other saline waters, will be of a lower temperature than the waters themselves, in consequence of the pure vapor of water only escaping from them, in the same manner as in *freezing*, that process excluding all other matter than pure water, not excepting even air, when the process is conducted under the most favorable circumstances.

If we expose water in an open kettle over a fire, the heat will gradually accumulate, with little loss of water, by vaporization, until it has attained the temperature and pressure due to the atmosphere, which we will assume to be 100° C.

This is the point of ebulition; and so rapidly does the vapor escape, that, however fierce the fire, no higher temperature can be given to the water in the kettle. Now, this is a most wonderful phenomenon, although one of the commonest in life. It is, nevertheless, but little understood, and the little use which has been made of that knowledge

is scarcely less wonderful. That mankind should have continued to grovel in the wake of Watt for more than eighty years, without having produced any economical improvement, either in the steam-engine or the condenser, is a fact which cannot be denied; while, and during the whole of that period, at least, it was well known that the *latent heat* in *steam*, constituting eight-ninths of the whole, was washed away in a flood of condensing water, without an effort being made to save it, although so palpably in the true direction of economical improvement in working the steam-engine.

I have recently had forwarded to me a translation of a document from some learned Professors of Berlin (relating to a matter in which I am interested), which avers that steam may evaporate more than its own weight of water, because at a high pressure it has more total heat than at a lower one. No wonder, then, that a similar error should be made by non-professionals in regard to a celebrated apparatus for distilling sea water, the steam from which is represented to have evaporated more than its own weight.

In the case of the Professors, I take it to be an oversight; but in the other case, it is simply an impudent trick of trade, asserted without the slightest foundation or knowledge, for no such result could possibly have been attained.

When steam is used for the purpose of evaporating water, the vapor obtained must necessarily be of a somewhat lower temperature, and, at the same time, its total heat will be less. That is admitted. But the latent heat increases in a much higher ratio than the total heat diminishes by reduction of temperature, according to the received theory. Each degree of temperature reduced causes a decrease =t.305 of the total heat, and, of course, the latent heat increases t.695, or its complement, for the sum of the temperature and the latent heat constitutes the total heat. Hence, the heat constituents of steam vary with its temperature, and a change in any one of them involves a change in all, the total heat being always represented by t.305+606.5. In ordinary condensation of steam, the *latent heat* is entirely converted into sensible heat on being absorbed by the water, the temperature of which is increased in proportion to the relative quantity used. As a rude illustration, take Fig. 1, in which the water is heated by a furnace (A) from 0° to 100°. It has absorbed 100 calorics and still remains

water. Pass this water over another furnace (B) of 5.37 the power, and it will not show any change of temperature, but will, nevertheless, have absorbed 537 calorics, which have passed through and carried with it a unit of water, which goes over as vapor into the condenser (C) containing the whole of the calorics absorbed from both furnaces (A and B). viz., 637, of which 537 are latent and only 100 sensible. Condense this vapor, and the 537 calorics will be converted into sensible heat in the abundance of water necessarily used in this, the ordinary mode of surface condensation. The water resulting from the condensation of the vapor remains at the same temperature as it had attained in the first furnace, viz., 100°; but it may be cooled down to any practical extent in a separate vessel, according to the quantity and temperature of the refrigerating or cooling medium. The quantity of water required on this system, for condensation and cooling, is rarely less than 60 units, and sometimes double that quantity may be required. In this case the latent heat is wholly and irrecoverably lost in the flood of cold water escaping at B′ with 537 calorics.

Now bring down the rider, Fig. 2. A and B remain and operate just as before, nor is there any change in the condenser; but the operation of the *condensing water* is wholly changed, and cannot exceed by weight an unit to an unit of vapor to be condensed.

The vapor descends (as before) within the condenser (C′) and becomes water, in consequence of the latent heat having gone into the *condensing water*, which enters at 0° and leaves at 90° (just as the furnace A raises water from 0° to 100°). After that it operates like the furnace B, and passes the remainder of the 537 calorics, viz., 447=(537—90), through the water without affecting its temperature. This effect is produced by removing about one-third of the pressure of the atmosphere (by an air-pump), which causes the water to boil on the outside of the condenser at 90° (at which temperature the latent heat in vapor is but 544 calorics), while on the inside, and under the full pressure of the atmosphere, it requires 100° to cause ebulition. The water at 90°, at first sensible, next follows; and thus the whole 537 calorics have gone through the condensing water, and gradually changed it into vapor, =.987 (nearly) of an unit, because (.987×544)=537 calorics is all that the vapor at 100° has to part with; hence, the condensing water must be .013=(1.—.987) less in weight than the vapor condensed.

We now place Fig. 3 as a rider to Fig 1, and we find it just the same as Fig. 2, so far as the condensing water increasing to 90° and the 447 calorics passing through it, as before.

Now, however, we have no air-pump; but, instead of it, we have a 100-caloric furnace, which operates the same as A in furnishing 100 calorics to the water; but, instead of being at the commencement of the operation, it precedes the end thereof. Consequently, but 10° of sensible heat are added to the 90° to make 100° of temperature from the "perpetual complementary furnace," which also supplies 90 calorics in addition, just as the furnace B supplies its 537 calorics, for in both cases the respective calorics pass through the water without affecting the temperature thereof.

We now see how to dispense with the furnaces A and B, and also the starting steam-pipe—by salvage of the whole of the latent heat from the vapor under condensation, amounting to 537 calorics, and complementing it with 100 calorics from the furnace aforesaid, which thus brings back vapor for the condenser in every particular similar to that supplied in Fig. 1.

It is scarcely necessary to say that any desirable pressure may be obtained to work a steam-engine on this principle of condensation. Nevertheless, a high pressure is not desirable; because, although the total heat increases therewith, the latent heat, which constitutes the salvage, decreases, as before explained.

In *starting*, without the "steam starting-pipe," the time will necessarily be increased, but not very considerably, because the apparatus will commence working as soon as the water boils over the *complementary furnace.*

Excluding high-pressure steam as dangerous and unnecessary, and the air-pump as a complication and a great source of accidents, I propose to operate with the simplest apparatus possible under the pressure of the atmosphere, in such a manner as to utilize the whole of the 537 latent calorics, still losing 100, although 70 of them are capable of salvage, theoretically at least; but I hope, ere long, to have the honor of showing you, Mr. President and gentlemen, the salvage which is obtainable, practically, in distilling sea water.

The *modus operandi* rests upon this basis, viz.: if, with its own weight of water, vapor can be condensed (which can only be done

by causing a portion of its latent heat to remain in that state), the resulting total heat must be complemented with as much as has been parted with in the vapor water, and thus become vapor again, precisely as before.

In the ordinary method of distilling sea-water, there must always be a considerable loss from blowing off the concentrated hot brine, in order to prevent scaling the boiler. This difficulty is effectually got rid of by the method which I have to propose, so far, at least, as that is concerned, thus:

If for every unit of distilled water obtained from the apparatus, an unit of brine is allowed to run to waste, it is obvious that the waste is double brine, and is represented by $2.=\left(\frac{2}{1}\right)$, the normal brine being 1. The reason is obvious, for we have the whole of the salt in the one unit of waste brine which was previously in two units of the normal brine. If it is desirable to reduce the strength of the waste brine and thus save the boiler, admit more brine to run to waste. Thus if two units of waste brine to one of the distilled water, then $\left(\frac{3}{2}\right)=1.5$ is the strength of the brine, if three times $\left(\frac{4}{3}\right)=1\frac{1}{3}$,—if four times $\left(\frac{5}{4}\right)=1\frac{1}{4}$.

If five times $\left(\frac{6}{5}\right)=1\frac{1}{5}$ is the strength of the brine. This principle also applies to alcoholic distillation from wash with great advantage, because all the alcohol may be abstracted at one distillation. The process is continuous, and there remains no sediment requiring to stop distillation to clean out.

We have seen that, according to Regnault, vapor at a temperature of 100° C. has 637 calories; and if we plunge an unit by weight thereof into 6.32 of water at 15° C., we shall have nearly 732 $(637+6.32\times15)$ calories in $7.32=(1.+6.32)$ units of water, at a temperature of 100° C. $=\left(\frac{732}{7.32}\right)$. In other words, one by weight of vapor at 100° C. will

raise the temperature of 6.32 times its own weight of water to its own temperature of 100° C. from 15° C.

The vapor retains, when condensed, its normal temperature of 100°, while the 6.32 of water absorbs all the latent heat, viz., 537 calorics, and $\left(\frac{537}{6.32}\right)=85°$ is added to the initial temperature of the condensing water. which thus becomes 100=(15+85).

Now, therefore, if we retain the original vapor water at 100° in a close surface-condenser, we have condensing water at the same temperature (100° C.), which requires 537 calorics to be added to one unit thereof to produce vapor having 637 calorics, as at the starting point, which is a gain of 85 calorics; and we have then 452=(5.32×85) calorics to run to waste, in 5.32 units of water at 100° C.

But the waste water will not exceed a temperature of 96° as it runs to waste, and, therefore, all less than $5.55=\left(\frac{532}{96}\right)$ will be salvage, to be added to that of 85 calorics out of 637, amounting to 13.34 per cent. In other words, for every unit of vapor water obtained, we may run five and a half (5.55) to waste, and still have the following advantage over the ordinary method:

1st. 13.34 per cent. salvage in the feed-water =85°=(100—15).

2d. No blowing through is required to clear out the concentrated brine from the boiler water, which, if blown off at double concentration $\left(\frac{2}{32}\right)$, will have to be supplied with water at 15° C., instead of 100°, causing a loss of 13.34 per cent., which, added to the former saving, makes the whole salvage =26.68 per cent. over the ordinary method.

3d. Less loss by radiation, by avoiding the use of steam as a heating medium, which requires a larger chamber, and, therefore, exposes more surface to radiation.

4th. More water will be evaporated by the same fuel, in consequence of the concentration of the brine not exceeding $1.12=\left(\frac{7.32}{6.32}\right)$, the boiling point being 100.721° C., instead of 2, when the boiling point is 101.288° C.

5th. The very low temperature (never exceeding 101° C.) at which the process is conducted, avoids any possible danger and greatly reduces the loss by radiation, and avoids scaling, while rendering unnecessary the sounding an alarm by blowing off vapor.

6th. Wear and tear of apparatus.

As these advantages are indisputable, it must be admitted that the system is economical, and that too, whether the latent heat is available or not.

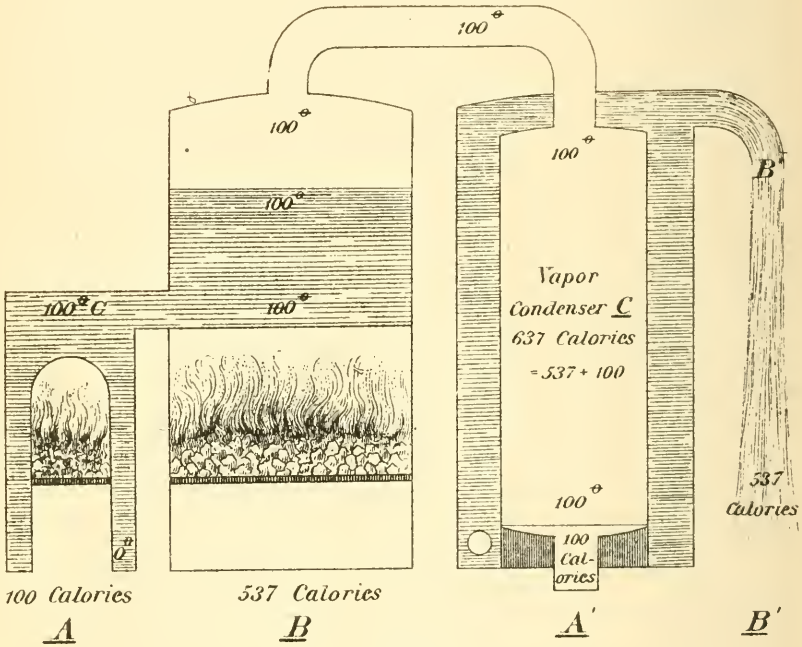


Fig. 1.

*Open to the atmosphere at A'* *B' with entire destruction of the latent heat*

*Three methods of Distillation.*

*Prosser's System of Distillation.*

*The pressure removed to about $\frac{2}{3}$ rd atmosphere at B" by air-pump.*

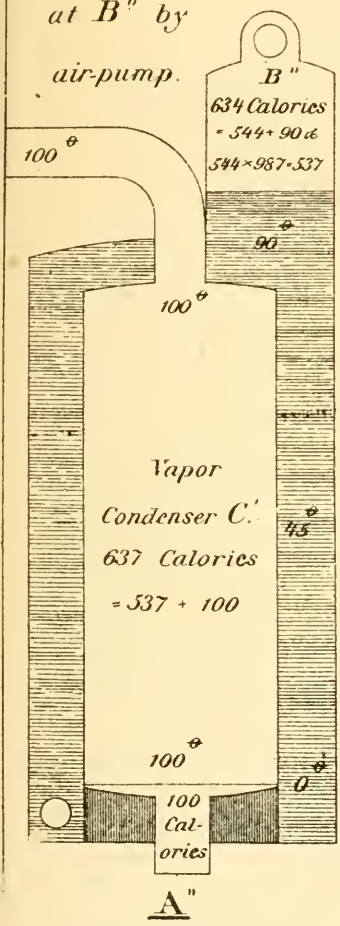


Fig. 2.

*B" with salvage of latent heat at a lower pressure*

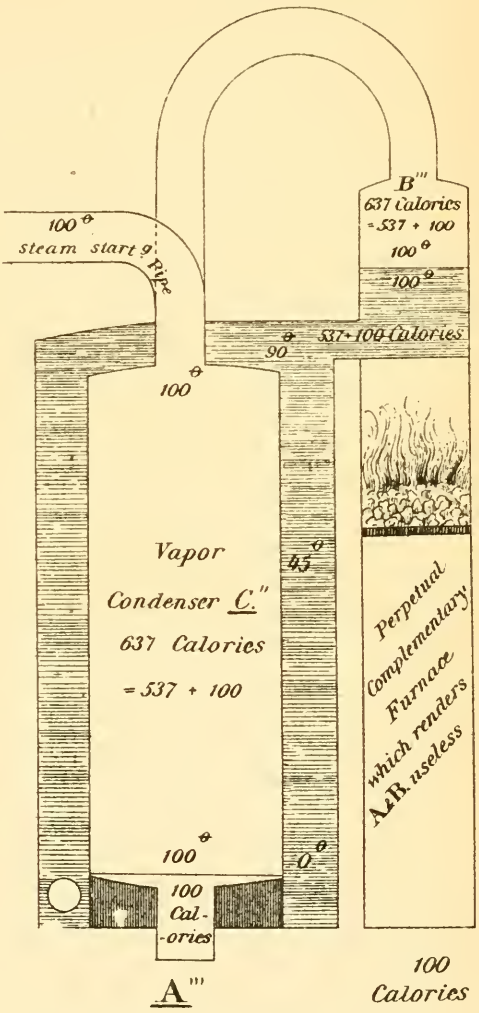


Fig. 3.

*B''' with entire salvage of latent heat.*

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# TRANSACTIONS.

## X.

## BÉTON-COIGNET, ITS FABRICATION AND USES.

A paper read before the Society March 3, 1869, by LEONARD F. BECKWITH, Civil Engineer, Member of the Society.

NOTE.—The substance of the following paper is contained in a report which I submitted to the United States Commission at the Universal Exhibition in 1867, together with later information on the subject.

### NATURE AND VARIETIES OF BÉTON.

*Definitions.*—Common béton, or concrete, is a conglomeration of sand, pebbles, broken stones, common lime, and water.

Common béton for marine uses is a conglomerate of similar stones, hydraulic lime, and water.

Béton-coignet, to which this paper relates, is an artificial stone formed of sand, lime, and water, and is used in blocks, or in continuous masses, for foundations, walls above and below ground, sewers, water-pipes, floors, pillars, arches, retaining-walls for embankments, aqueducts, reservoirs, cisterns, and the entire walls of buildings.

The elements are the same as those of common mortar for masonry; but the relative proportions of each, the method of making, and the results are different.

*Theory of Concretion.*—Common mortar being composed of sand, lime, and water, the theory of its concretion may be briefly stated as follows:

1. The chemical changes which occur from the contact of quicklime (oxide of calcium) and water, produce hydrate of lime, and the subsequent absorption of carbonic acid from the air, displacing the water, produces carbonate of lime.

2. The strength and hardness of mortar result from the cohesion of sand and carbonate of lime, and from the crystallization of the carbonate, which grasps and binds the grains of sand.

3. Homogeneity depends upon the equal and uniform diffusion of the lime among the sand.

4. An excess of lime in proportion to sand produces great shrinkage and imperfect crystallization, and leaves the mass brittle and weak.

5. An excess of water in proportion to lime cannot combine with it, but lodges between the particles of sand and lime, and, by slow evaporation, leaves the mass porous and friable.

6. The practical difficulties are: first, to find the proportions in which the elements will best combine; and, second, to produce the conditions most favorable to their combination.

*Observation.*—Common sandstone is usually composed of large quantities of silicious sand and small quantities of some cementing substance; oxide of iron, clay, carbonate of lime, &c., &c.; therefore,

7. The right elements being properly mixed and in due proportions, each grain of sand enveloped in a coating of moistened lime, and all the grains brought into contact—the conditions, in short, being right—crystallization should be simultaneous and uniform throughout the mass.

This line of thought, pursued through a long series of experiments, has produced the béton-coignet, a kind of calcareous sandstone of great durability, admirably adapted to numerous and common wants, and of small comparative cost, its elements being found in abundance in all countries.

*Composition.*—A large quantity of sand, a smaller quantity of lime, and a little water—only water enough for quick assimilation with the lime, to prepare it for crystallization, and lime enough, when uniformly diffused, to form a thin coating to the grains of sand.

These ingredients, when properly manipulated, are barely moist, but the preparation is complete and ready for use.

The mixture is handled with shovels and transported in carts and wheel-barrows, the same as dry sand. It may be spread on the ground for foundations or floors, placed in moulds for blocks of different models and sizes, and shovelled into cribs of planks to give shape to walls, or dumped into trenches provided with wooden forms for the sides and arches of sewers.

The béton, when placed, should be slightly compacted by the use of light hand-pestles, to perfect the contact of particles and hasten the processes of solidification. In a short time, the spontaneous action which follows will be complete, and the forms may be removed.

*Varieties.*—Bétons cemented with different sorts of lime attain the same final solidity and strength, but require various periods of time for consolidation.

Common lime sets slower than hydraulic lime, and the latter sets slower than cement; in other words, crystallization is quicker in each of the varieties named, reversing the order.

Hydraulic lime, in addition to quicklime, contains alumina, oxide of iron, silica, magnesia, &c., &c.; and cement consists of similar elements, with the alumina, silica, &c., augmented. The latter hardens quicker than the preceding, and gives a finer and smoother surface.

Consequently, when time is of importance and structures are required for immediate use, hydraulic lime is substituted for common lime; and, to quicken the result, a portion of cement is usually added.

Lime for common mortar should be slaked at least twenty-four hours before it is mixed. For béton-coignet the lime should be slaked but two or three hours before it is mixed; barely enough water should be applied to reduce it to powder, and the supplementary water applied in mixing should be only sufficient to render the lime damp and adhesive, leaving still in the lime a capacity for the absorption of water. The natural affinity of the lime for moisture being thus incompletely satisfied, renders the taking or crystallization more vigorous and rapid, and

promotes the subsequent carbonation by the readier absorption of carbonic acid.

The slaked lime, when used, should be in fine powder, and it is sometimes passed through a wire sieve, of about 1 000 meshes to the square inch, to free it from unslaked and unburnt particles.

Coarse sand makes a harder béton than fine sand, and the taking is stronger. Clean, sharp river sand, one-twentieth to three-twentieths of an inch in diameter, is best; all kinds, however, are used, and, if it contains earthy particles, more lime is required. Fine sand requires greater care and more packing for consolidation.

Pozzuolana or crushed brick should not be added, as they render the béton porous and hygrometric.*

Béton-coignet may be described, generally, as composed of—*sand*, 4 to 5 parts in volume; *lime*, common or hydraulic, 1 part in volume; *cement*, $\frac{1}{4}$ to $\frac{3}{4}$ of 1 part in volume; *water*, variable—$\frac{1}{10}$ of the total weight of the mixture being considered a maximum.

### FABRICATION AND PROPERTIES OF BÉTON.

*Mixing.*—The machinery most in use for mixing consists of a vertical cylinder, an elevator, and a locomobile for working the machine.

*Mixing Cylinder.*—The mixing cylinder is 1 foot 11½ inches interior diameter, and 4 feet 1½ inches high. It is constructed of boiler-plate, and rests on a cylindrical base of cast-iron, with projecting arms for supports and for sustaining the bottom plate, which is suspended and immovable.

A vertical wrought-iron shaft, 2¾ inches square, passes through the centre of the cylinder, to which shaft from 10 to 16 curved arms of elliptical section are attached, and revolve horizontally for mixing the sand and lime. A revolving distributor receives the lime and the sand as they enter the cylinder at the top from the conducting trough, and distributes them equally around for mixing.

Attached to the sides of the cylinder are short, stationary, horizontal arms, forming, with the movable arms, breaks for dashing and mixing the sand and lime. Three warped or helicoidal blades are attached to the lower part of the shaft for forcing and ploughing the mixture down-

* Sand containing salt should be avoided for the same reasons.

wards and outwards, and three cycloidal arms revolve horizontally near the floor of the cylinder to expel the mixture at the sides opening around the bottom. This circular opening is enlarged or diminished by moving up or down a band of iron which passes around the cylinder, and which works on vertical iron guides. Finally, below the bottom plate of the mixing cylinder is a second plate, which is attached to the vertical shaft and revolves with it.

*Elevator.*—The elevator is supported on a double frame of wood, with an inclination of 1 of height for 1½ of base, and consists of 13 small sheet-iron buckets attached to an endless chain revolving round two drums. Each frame consists of two pieces united by a cast-iron joint, and strengthened at intervals with iron plates in which are set rollers.

*Locomobile.*—The apparatus is run by a portable steam engine, of 8 to 12 horse power. The locomobile is non-condensing and double-acting, and is provided with a cylinder for heating the water by the escaped steam; the whole is placed on springs and rests on wheels. The number of revolutions per minute is about 100. Length of stroke 16 inches; diameter of steam cylinder 8 inches. The pressure of steam is 5 atmospheres, corresponding to 73 pounds per square inch.

*Driving Gear.*—The power is transmitted by a belt to the shaft of the upper drum of the elevator, and thence by a crossed belt and a set of bevelled wheels to the vertical shaft of the mixing cylinder. The apparatus is provided with a fly-wheel.

The mixing cylinder may be worked by horse power, and in that case the elevator and chief part of gearing are dispensed with.

*Rate of Production.*—A mixing cylinder of 1 foot 11½ inches diameter and 4 feet 1½ inches high, run by a locomobile of about 8-horse power, will produce daily from 100 to 130 cubic yards of béton.

The same apparatus run by a one-horse power will produce daily from 12 to 15 cubic yards.

*Details of Fabrication.*—Alternate layers of sand and slaked lime in powder are thrown into a heap, about a cubic yard in quantity; are mixed with shovels on the ground, and then passed into the buckets of the elevator. The latter discharges into the inclined shute which con-

ducts to the mixing cylinder. When cement is added it should be previously well mixed with a little water in a trough, through which revolves a small shaft with arms, and then added in small quantities to the materials in the cylinder. The mixing apparatus being in operation, small quantities of water, a glass or pint at regular intervals of time, are poured in through a rose at the top of the cylinder by a boy stationed for that purpose. To insure regularity in the distribution, a circular pipe round the upper end of the cylinder is sometimes used. It is pierced at regular intervals with a series of small holes, through which the water, supplied from the reservoir above, trickles into the cylinder. The quantity of water to be added varies with the materials, and must be regulated by observation, the foreman personally controlling the supply. The béton issuing from the cylinder should be moist, granular to the touch, and when made into a ball and slightly compacted in the hands, should retain its form and harden rapidly. The mixture in the lower part of the cylinder is forced downwards by the helicoidal arms and then outwards by the cycloidal arms, through the opening round the cylinder. The expulsion through the opening pushes it off the bottom plate at every point of its circumference, and falling on the revolving plate it is carried round till arrested by a fixed scraper which collects and shoots it off on to the ground or into boxes.

A thorough mixing is important for a rapid setting and hardening of béton. For ordinary masonry one mixing is sufficient; for finer work a second mixing in the same apparatus is advisable. The first run or two is always put back into the mixing cylinder, as it is generally imperfectly mixed.

When a rapid taking is necessary, as in winter work, etc., the mixture may be artificially heated up to 176° or 212° Fahr. (80° to 100° C.) during the operation of mixing. For this purpose heated air or steam is introduced into the mixing cylinder through a pipe bored with small openings, or else the cylinder itself may be heated by a spiral tube in which steam or hot water circulates. Heating quickens the drying and hastens the taking and hardening of the materials; it also darkens the color.

*Packing.*—The béton taken directly from the mixing cylinder is wheeled in barrows to the building, shoveled into moulds or forms in successive layers about 6 inches thick, and each layer steadily com-

pressed with wooden-hand pestles or rammers, weighing from 15 to 30 pounds. The upper surface of each layer should be left rough or roughened with an iron rake to produce a good joint with the layer above.

Generally $1\frac{6}{10}$ cubic yards of loose material from the mixing apparatus will compact into a cubic yard of wall. The subsequent hardness of béton depends greatly on packing.

*Moulding.*—There are two methods of moulding: *First, Moulding in Place.*—Walls for buildings are constructed in sections of about 3 feet in height, and 10 to 15 feet in length. For this purpose a crib or framework and boards, forming two sides of a box, is constructed with an interior space equal to the thickness of the intended wall; the sides of the crib are kept in place by small iron rods which connect them, passing through the wall and to be subsequently withdrawn. The loose béton is shoveled into the crib and compacted with the pestle; subsequently the connecting rods are withdrawn, the sides of the crib or mould are lifted up, a second section is formed in like manner on the top of the first, and the work continues in this way till the wall reaches the required height. *Second, Moulding in Blocks.*—Building blocks of various sizes, hardness and forms, with or without ornaments, are made of béton in moulds, in the same manner as sections of wall above described, and the blocks are laid with joints of mortar like other stone. Blocks and slabs for balconies, steps, fountains, columns, cornices, pilasters, etc., are formed in like manner.

*Properties.*—Different properties of béton-coignet tested at the *Conservatoire des Arts et Métiers*, give the following results, indicated in the annexed table.

*Experiments on the Crushing Strength of Béton-Coignet, made at the Conservatoire Impérial des Arts et Métiers, by Mr. P. Michelot, Chief Engineer in the Ponts et Chaussées, Paris, July, 1864.*

| Date of Fabrication of the Samples. | Age of the Samples | Composition of the Samples Experimented on. | Dimensions in Centimetres. | | | Weight in Kilograms of a Cub. Metre. | Crushing Strength | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length. | Breadth | Height. | | In Kilograms, Total. | In Kilog'ms per Sq. Centim. | In Pounds, per Square inch. | |
| | Yrs. mo. | | | | | | | | | |
| February, 1862* | 2 6 | River Sand, Half Size.. 4<br>Lime of Argenteuil (slightly hydraulic)... 1<br>Cement of Paris..... ½ | 7.60<br>5.20 | 5.80<br>2.40 | 8.10 | 2,085 | 12,809.678<br>16,213.541 | 226.48<br>286.66 | 3,269.56<br>4,130.77 | Fissured—Composition of vaults of City Barracks. |
| January, 1862*.. | 2 7 | Coarse Sand..... 5<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ¾ | 7.80<br>5.10 | 5.90<br>3.40 | 5.70 | 2,179 | 20,249 058 | 319.59 | 4,545.56 | The small lateral prism was first crushed, but the larger prism resisted well. |
| January, 1862.. | 2 7 | River Sand..... 4<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ⅓ | 7.60 | 5.20 | 8.10 | 2,093 | 11,291.441 | 293.31 | 4.171.78 | |
| February, 1863* | 1 6 | Common Sand..... 5<br>Lime of Argenteuil..... 1<br>Cement of Paris... .... 1 | 7.60<br>5.00 | 5.70<br>2.40 | 8.10 | 2,227 | 15,711.941 | 284.02 | 4,039.64 | One corner of the sample was damaged previous .to the experiment. |
| February, 1863* | 1 6 | Common Sand..... 5<br>Lime of Argenteuil..... 1<br>Cement of Paris..... 1 | 7.60<br>5.00 | 5.70<br>2.40 | 8.10 | 2,196 | 17,452.641 | 315.49 | 4,546.21 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| February, 1862.. | 2 | 6 | Coarse Sand..... 4<br>Lime of Thiel(hydraulic) 1<br>Boulogne Cement..... ½ | 10.10 | 8.30 | 10.00 | 2,277 | 32,866.798 | 392.06 | 5,649.58 | |
| November, 1862. | 1 | 9 | Mixed Sand..... 4<br>Lime of Thiel..... 1<br>Boulogne Cement..... ¾ | 7.60 | 5.75 | 8.10 | 2,348 | 21,761.241<br>22,729.641 | 497.98<br>529.13 | 7,175.89<br>7,495.07 | Fissured. |
| November, 1862* | 1 | 9 | Coarse Sand, washed.... 4<br>Lime of Argenteuil..... 1<br>Boulogne Cement ..... ¾ | 7.60<br>5.05 | 5.80<br>2.20 | 7.90 | 2,271 | 21,531.741 | 390.14 | 5,549.00 | |
| November, 1862* | 1 | 9 | Coarse Sand, washed.... 4<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ¾ | 7.70<br>5.10 | 5.65<br>2.20 | 8.00 | 2,243 | 20,642.041 | 377.16 | 5,364.38 | |
| May, 1863*..... | 1 | 3 | Sand of Vésinet..... 4<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ¼ | 7.80<br>5.15 | 5.65<br>2.40 | 8.05 | 2,142 | 10,642.441 | 188.60 | 2,682.48 | Composition of the Church of Vésinet. |
| May, 1863*..... | 1 | 3 | Sand of Vésinet..... 4<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ¼ | 7.80<br>5.20 | 5.60<br>2.60 | 8.05 | 2,146 | 10,456 141 | 182.80 | 2,631.14 | |
| 1862..... | .... | | River Sand, screened... 4<br>Lime of Argenteuil..... 1<br>Cement of Paris..... ¾ | 5.20 | 5.20 | 8.10 | 2,091 | 7,628.154 | 282.11 | 4,012.48 | |

* *Observation.*—The samples marked with an asterisk have the form of a T, the double numbers in the columns of length and breadth indicate the size of the two rectangles composing the total surface.

An examination of the preceding table will show that the strength or bearing power of each variety of béton is sufficient for ordinary uses, but that the differences are great; and a more careful study will trace these differences to the properties of various sands, to proportions of sand, lime, cement and water, and to the peculiar ingredients inherent in the various limes derived from different localities.

But an elaborate explanation of the table would have no particular value, as similar substances derived from different localities are never exactly alike, and the best mixture in each particular case must be ascertained by actual experiments, which are easily made, the results being simple and obvious.

Most of the bétons in the preceding table are stronger than is necessary for ordinary uses, and if used, the thickness of the structures as compared with common masonry may be diminished. For the more common purposes bétons of more sand and less lime are used.

The tensile and bearing strength of béton is variable, as is that of every kind of stone; the tensile strength of béton-coignet varies from 288 to 426 pounds per square inch, and the crushing strength from 2,634 to 7,495 pounds per square inch. The following table shows the range of strength and relative strength of the different kinds of building materials named :

| | Mortar. | Common Béton (Concrete). | Béton-Coignet. | Brick. | Lime-stone. | Sand-stone. | Granite. |
|---|---|---|---|---|---|---|---|
| Crushing strength in pounds per square inch..... | 280 to 2100 | ..... | 2634 to 7495 | 550 to 1700 | 4000 to 5500 | 2200 to 5500 | 5500 to 11000 |
| Tensile strength in pounds per square inch..... | 50 to 290 | 77 to 360 | 288 to 426 | 115 to 300 | 120 to 864 | 180 to 900 | .... .... |

The specific gravity of béton varies from 2.09 to 2.35, and a cubic yard weighs about 3 700 pounds.

APPLICATIONS OF BÉTON-COIGNET.

*Warehouses, Churches, Granaries, Cellars, Foundations.*—Structures, buildings, and foundations of solid masses of béton suffer less than ordinary materials from unequal settling of the ground, because the béton

exactly fills the excavation prepared for it. Underground rooms and cellars built of it are particularly free from damp.

The railway station at Suresnes, several houses at St. Denis, the Gothic church at Vésinet, etc., are examples of this kind, and from the absence of joints are as if made of one block of stone.

Cheap dwellings for workmen are now in course of construction in several localities in France.

A small house of béton-coignet was exhibited at the Champ de Mars with specimens of arches, piers, slabs, statues, fountains, etc., finely moulded and well made by Mr. Coignet.

The materials for common work of the above kind are five parts of sand, one of lime, and the ordinary quantity of water.

*Arches and Vaults.*—Arches and vaults built of a single block of béton, act like a slab which has been partially hollowed out beneath; they, consequently, have less lateral thrust than if composed of voussoirs of separate blocks of stone. The versed sine of these arches and vaults is generally from $\frac{1}{10}$ to $\frac{1}{15}$ of the span. The rapid setting of the material enables the centres to be struck within a few days.

Various experiments have been made, with good results, to test the strength of béton for arches. In December, 1864, the engineers of the Ponts et Chaussées experimented on an arch of béton, of 39.36 feet span, 0.82 feet thick at the crown, and 3.28 feet wide. At the end of a year a rectangular block, 1.148 feet wide by 0.656 feet long and 0.82 feet deep, was first cut out of each side of the crown, leaving a section 0.82 feet deep by 0.984 feet wide to sustain the whole thrust of the arch.

This section was successively diminished in width from 0.984 feet to 0.328 feet, then to 0.197 feet, still retaining the depth of 0.82 feet, and finally to 0.164 feet, with a depth of 0.656 feet, at which point rupture took place. This experiment proves, in a satisfactory manner the enormous resistance to crushing which béton-coignet is capable of.

An experimental arch on the Quay de Billy has a span of 55½ feet; versed sine, 4 feet; thickness of crown, 14 inches, with good results.

Béton is used for arches and vaults in the structures of the Northern Railway at Paris, the new prison of the Madelonnettes, and in the new

barracks of Notre Dame. In the latter an arched vault was built of 18 feet span, 1½ feet versed sine, 8½ inches thick at the crown, with surface of 14 square yards, on which experimental weights of 47 tons were placed for a fortnight without damage. Béton was afterwards used for all the similar arched vaults in the building, giving a surface of 3,588 square yards.

At Vitry-en-Perthois a bridge of béton has been built, consisting of 2 arches, each of 54.94 feet span and 4.26 feet versed sine. This bridge resists a pressure at various points of 711 pounds per square inch, and its cost is the same as if made of wrought-iron girders arched with brick.

In the winter of 1866, several arches of béton-coignet, 18 feet span, were built under the stair-approach from Westminster Bridge to the southern embankment of the Thames; and, notwithstanding some very severe frosts, the work suffered no delay and gave good results. As a precaution against frost, it is prudent to cover the work with tarpaulins.

At Aubervilliers the machinery of a considerable saw-mill is placed on an arch of 33 feet span; versed sine, 6½ feet.

Mr. Coignet exhibited at Paris, in 1867, several arches of béton; also half an arch springing from a pier and cut square off at the crown, maintaining itself in that position by its great tensile strength alone.

The ventilation of the Exhibition Building at the Champ de Mars is effected by underground works consisting of a series of circular and radial galleries, arched with béton, span about 10 feet, for the circulation and supply from below of cool air through openings in the floor.

The outer gallery is 33 feet in width, 8.2 feet high, and 1,443 yards in length. The groined arches of béton, 5½ inches thick at the crown, are supported on two rows of béton pillars, 1 foot 2 inches square and 864 in number, carrying a roof, the upper surface of which forms a béton floor of 15,873 square yards of surface.

The quantity of béton consumed in these galleries was 353,166 cubic feet.

The materials of this structure were: four parts of sand, one of lime, and one-half part of Portland cement.

*Walls.*—The embankment on which runs the Avenue de l'Empereur, at the Trocadero, for a quarter of a mile is supported by a wall of béton about 40 feet high. The outer side is strengthened by pilasters ; the inner side consists of a series of arches at right angles to the wall, built one upon the other and extending into the embankment, forming a bearing for the mass of earth, and diminishing its lateral pressure against the wall. The wall and arches are a solid mass of béton.

The breast-wall of the cemetery of Passy, 50 feet high, is being built of béton.

The steeple of the Gothic Church of Vésinet is constructed of béton, 130 feet high, and shows no sign of weakness.

*Floors, Terraces, Roofs.*—If the area does not exceed 13 or 16 feet in width, a slab of béton 10 or 12 inches thick will be strong enough to sustain itself ; if the area be greater, double T-joists of iron should cross the space for ceilings, floors, etc., and the slabs of béton may be made thicker or thinner, depending on the distance of the joists one from another, the flanges of which form the holding of the slabs.

Joists being thus placed, and a temporary scaffolding or floor of boards erected underneath, the béton is dumped upon it and packed ; the edges hold upon the flanges, the béton hardens, the scaffolding is removed, and the ceiling remains firm. If the upper side should serve for a floor also, the béton should be laid thicker, and carried over the joists so as to form a smooth surface above them.

Béton may be successfully used for fire-proof roofing.

Béton for this work should be five parts of sand, one part of lime, and one-fourth part of cement.

*Flagging, Sidewalks.*—Béton being impervious to water and without joints, no moisture is absorbed beneath, if the ground is properly drained ; therefore, no heaving or disturbance results from frost in the ground. Flagging and floors of béton for courts, stables, cellars, coach-houses, schools, railway stations, warehouses, etc., etc., are much used.

Béton has been proposed for paving streets, and a few experiments have been made with satisfactory results as to hardness and strength. The first-cost of a béton pavement would be greater than that of a macadamized road and less than that of a stone pavement.

*Foundations for Machinery.*—Foundations of béton for machinery are cheaper and as good as the best masonry of stone. The excavation for the foundation being made, the béton is dumped in and packed, the moulds of board giving the desired shape to the foundation. The spaces for foundation bolts are made by packing the béton round 4 or 5-inch wooden cylinders, which are subsequently withdrawn.

For engines, a cubic yard of béton corresponds to a horse power, and a 30-horse power engine should have 30 cubic yards of foundation.

Foundations of béton for water-wheels and turbines may be seen at St. Maur ; for steam-engines, at the percussion-cap factory at Paris, the tobacco factory at Châteauroux, the glass works at St. Gobain, etc., etc. At Oyssel, a steam-engine of 400-horse power, which works admirably, rests on a block of béton 7 yards in thickness ; and at the Exposition of 1867 a great portion of the machinery was placed on béton foundations laid in winter, and worked well.

Composition : sand five parts, lime one part, cement one-fourth part.

*Sewers, Aqueducts, Water-pipes.*—The use of béton for sewers and water conduits of all kinds is one of its most successful applications. A sewer thus constructed is impervious to water, and does not need an interior coating of cement. These sewers require no repairs, resist perfectly the pressure of the earth around, and have nothing to fear from settling, as the material fills the trench exactly.

The process of building a béton sewer is very simple. A trench is cut as usual, a floor of béton laid on the bottom, a framework of timber and boards is introduced, as for masonry, to give form to the sides and arch ; the béton is dumped and packed by the commonest labor, the woodwork removed within a few hours, and the sewer is finished and ready for use.

The curved surfaces which are used to a great extent in every work connected with water, are very expensive when built of cut stone or brick. When made of béton they are shaped with simple forms of boards, and the surfaces smoothed and turned by the workman with his trowel, when the material has been packed. All angles, joints, inequalities of surface, etc., which present obstacles to the flow of water are thus entirely avoided.

*Proposed Substitution.*—The sewers of Paris in 1852 comprised a

total length of 97 miles, their height not exceeding six feet. In 1862 the sewers had attained a length of 105 miles, and in February, 1869, a total length of 310 miles, with a height varying from six to nearly ten feet, and a width of from five to thirteen feet. Including the projected ones, the total length will eventually be 360 miles. Up to 1869, thirty miles of main and branch sewers had been made of béton-coignet in Paris, and its use for this purpose is rapidly increasing.

The regulations for sewers requiring walls of 10 inches of stone masonry, admit walls of 8 inches of béton; their construction of béton requires less time; the economy in masonry is reckoned at 30 per cent., and the saving on the whole at 20 per cent.

*Dimensions and Cost of the Principal Sewers of Béton in Paris.*

| Type of Sewer. | Dimensions of Sewer. | | Area in square yards of Cross-section of Sewer. | Length in yards of Inner Circumference of Cross-section of Sewer. | Thickness of Wall in inches. | Cubic feet of Béton, per linear foot of Sewer. | Entire Cost in Paris, per linear foot of Sewer, including Cost of Excavation, Centring, and Masonry. |
|---|---|---|---|---|---|---|---|
| | Greatest Height in feet. | Greatest Diameter in feet. | | | | | |
| | Feet. | Feet. | Sq. yards. | Yards. | Inches. | Cub. feet. | $ c. |
| Main Sewer No. 8. | 9.186 | 7.546 | 6.045 | 8.667 | 10.63 | 26.156 | 5 92 |
| " 9. | 9.022 | 6.562 | 5.071 | 8.503 | 9.45 | 22.075 | 5 00 |
| " 10. | 7.874 | 5.641 | 3.959 | 7.170 | 7.87 | 15.608 | 3 53 |
| " 11. | 4.493 | 2.296 | 0.969 | 4.044 | 10.25 | 9.257 | 2 35 |
| " 12. | 7.054 | 4.265 | 2.894 | 6.492 | 7.87 | 14.639 | 3 31 |
| Branch Sewer No. 1. | 6.562 | 3.281 | 1.794 | 5.574 | 7.87 | 12.465 | 3 18 |
| " 2. | 6.234 | 2.524 | 1.419 | 5.301 | 7.87 | 11.948 | 3 04 |
| " 3. | 5.577 | 2.524 | 1.292 | 4.263 | 7.87 | 11.087 | 2 84 |

Water-pipes of béton are made at half the expense of iron, and they cost little for repairs. The whole of the underground drainage of 40 acres, roofed by the Palace of the Exposition, was through béton pipes of 12 to 16 inches tube, discharging into a main sewer of béton, 5 feet high by 2 feet wide, which emptied itself into the city sewers. The total length of the pipes and sewers was 8,166 yards, and the cubic contents of the materials used in them amounted to 264,825 cubic feet.

For the sewers of Paris, and for this service, the following proportions of materials were used :

175 cubic feet of sand (corresponding to 5 parts).

35 cubic feet of hydraulic lime (1 part).

550 pounds of heavy Paris cement, equivalent to Portland cement (½ part).

*Cisteras, Reservoirs, Tanks, Cesspools.*—These, when built of masonry and coated with cement, are impervious to water, but need constant repairs ; of béton, they are equally impervious, require no coating of cement, cost less, and are more secure. The centres are frequently struck six hours after the completion of the work.

A cistern 39 feet in depth, 5 feet in diameter, with sides of ten inches in thickness, after two days receives water, and remains sound an indefinite period.

The cesspools of béton authorized by the Prefect of the Seine, in 1862, are without cement, hold good and are water-tight ; structures of this kind are adopted for the Grand Opera House now building, and for the great railroad stations, etc., etc.; cesspools of béton are built from 8 inches to 12 inches thick, instead of 20 inches when built of stone masonry.

Gasometer tanks of large dimensions, 130 feet in diameter, 49 feet in depth, are built of béton-coignet, at Rueil and St. Denis. The difficulties of making structures of this size in masonry water-tight are said to be much less in béton.

Composition : five parts of sand, one of lime, and one-half part of cement.

### Marine Structures.

*Extract from Report to the U. S. Commission, by L. F. Beckwith.*

"For the foundations of breakwaters and piers, stones of irregular and various sizes are used, but small stones are preferred. Being cast into the sea without order, and left to find their position as they sink, small stones pack closer and form beds more solid than large ones ; they are also less liable to disturbance than large stones from the 'hydraulic

press action ' of waves arrested in their horizontal movement and thrown downwards.

" Banks or ridges with more or less sloping sides are thus raised from the bottom of the sea, nearly to the surface of low tide ; and upon these, walls of masonry are built of sufficient height and thickness to resist the force of the sea.

" The force of the waves against a vertical wall, as measured in different localities, shows the following results, in weather ranging from ordinary to tempest: At Cette, in the Mediterranean, from 14.000 to 24,000 pounds per square yard ; Bell Rock, Scotland, as high as 30,675 pounds per square yard ; island of Skerryvore, Scotland, 5,000 to 19,000, and 55,760 pounds per square yard ; Cherbourg, 36,000 to 55,000 pounds per square yard.

" The horizontal movement arrested by a wall in deep water becomes vertical, and produces a descending wave of great force, which tends to excavate and sweep away the bank and undermine the wall.

" The banks or foundations are, therefore, protected by covering the slopes with large blocks of stone, of sufficient size and weight to resist displacement by the descending waves, and in very exposed situations the talus of blocks thus formed is raised above the surface to afford protection also to the wall.

" The difficulties and expense of obtaining blocks of stone sufficient in size and abundance for this purpose have led to the use of artificial blocks of concrete. These blocks are also extensively used to form the interior of walls and piers, the facings being of stone. In solidity and strength they are equal to the purpose ; but they suffer more from the action of sea-water than the best kinds of stone, which is attributable to the ingredients in the cementing substance.

" *Hydraulic limes.*—Hydraulic limes are exceedingly variable in their elements, but may be divided into three general classes—silicious, aluminous, and cements.

" *Silicious limes.*—Limestone composed of carbonate of lime, intimately mixed with fine silicious sand, after burning, leaves 70 to 80 per cent. of quicklime, and 30 to 20 per cent. of silicate of lime, forming an hydraulic lime usually called 'silicious,' and expressed by the formula :

" $CaO.+SiO^3$. $3CaO$.

Slaking of this produces hydrate of lime and hydrous-silicate of lime ; formula :

"n. CaO. HO.+$SiO^3$. 3CaO. 6HO.

"*Aluminous limestone.*—Limestone containing 8 to 18 per cent. of clay, the principal elements of which are hydrous-silicates of alumina, after burning, leaves 70 to 80 per cent. of quicklime, and 30 to 20 per cent. of mixed silicates and alumina, forming an hydraulic lime called 'aluminous,' which, after slaking, is expressed by the formula :

"n. CaO. HO+$SiO^3$. 3CaO. 6 HO + $Al^2$ $O^3$. 3CaO. 6HO.

"*Cement.*—Limestone containing from 18 to 36 per cent. of clay, which leaves, after burning, quicklime, silicate of lime, alumina, silicate of alumina, produces 'hydraulic cement,' which, after slaking, contains hydrates of the preceding elements.

"Hydraulic limes and cements usually contain, in addition to the substances above enumerated, small quantities of oxides of iron, silicates of alumina and magnesia, sulphate of lime, etc.

"Mortar properly made of either of these limes crystallizes simultaneously, and sets quickly and strongly, though the presence of magnesia and sulphate of lime is detrimental to good setting, as these bodies crystallize slower. Oxide of iron does not impede the setting.

"Action of the Sea.

"The action of sea-water on hydraulic mortars is excessively complicated. The elements of lime, as above shown, are variable, and the salts of magnesia, carbonic acid, and sulphuretted hydrogen in sea-water are variable, and differ in localities but little removed from each other.

"I do not propose to follow in detail the results of the observations and experiments which have been made of various sea-waters on different sorts of hydraulic mortar.

"The mortars are all exposed to the mechanical action of the sea, and to the chemical action of the salts and gases which it holds in solution ; they are sharply attacked, and the effect is considerable before the hydrate of lime on the outer surface is converted into carbonate of lime by the absorption of carbonic acid from the water and air. The crust of carbonate of lime thus formed resists the

chemical action of the sea, and the protection thus given to the interior is increased, in some cases, by the growth of sea-shells and of marine plants. The waste is thus diminished, but it is never extinguished; the destruction goes on, and the best hydraulic mortars are gradually eaten away.

"Blocks of concrete contain more mortar than masonry of dressed stone; they are, consequently, more exposed to waste from the causes in question, and are sooner destroyed.

"Many remedies have been proposed, and numerous trials of them made, but hitherto without important and permanent success. The method proposed by Mr. Coignet is to get rid of the hydraulic limes and their perishable ingredients by the substitution of common lime as the cementing substance.

"Experiments of Mr. Coignet.

"Time is evidently required to test experiments of this kind, and those of Mr. Coignet are too recent to prove conclusively success or failure. His method of experimenting is by continually diminishing the quantity of hydraulic lime and cement, and continually increasing the proportion of common lime in the composition of his blocks. The blocks are placed in exposed positions, in different localities, to the action of the sea-water, and followed by periodical examinations and records of the progressive results of the experiments.

"His first experiments were begun, by order of the Government, in November and December, 1858, and January, 1859, on the Socoa breakwater at St. Jean de Luz, in a very exposed situation. The blocks were of several kinds, as follows:

"*First series of Blocks.*—Blocks made several months before being placed in the sea:

"1st. Blocks composed of seven parts of sand and one part of common or fat lime.

"2d. Blocks composed of seven parts of sand and one part of lime, slightly hydraulic.

"3d. Blocks composed of seven parts of sand and one part of fat lime, and one-fourth to one-half part of cement.

"4th. Blocks composed of seven parts of sand, one part of lime slightly hydraulic, and one-fourth to one-half part of cement.

"These blocks are all alike in good condition at this date (1867), and have resisted the action of sea-water with satisfactory results. They are compact and hard, and the only effect noticed has been the wearing of the edges of the blocks and the rounding off of the angles, produced by the friction of pebbles and the general mechanical action of the sea. No difference has yet appeared in the durability of blocks made of common lime, and those containing hydraulic cement.

"*Second series of Blocks.*—This series is composed of 12 small blocks made on land, and allowed to harden for eight days before being placed in the sea.

"Six blocks were composed as follows :

"1st. Seven parts of sand, one part of fat lime.

"2d. Seven parts of sand, one part of fat lime.

"3d. Seven parts of sand, one part of artificial hydraulic lime, made of fat lime and clay.

"4th. Seven parts of sand, one part of lime, slightly hydraulic.

"5th. Seven parts of sand, one part of hydraulic lime.

"6th. Seven parts of sand, one part of very hydraulic and silicious lime.

"The remaining six blocks were composed as follows : Each of seven parts of sand, one part of the same varieties of lime as the above blocks, with the addition to each of one-fourth to one-half part of cement.

"This series of blocks has completely resisted until now (1867) the action of the sea, and shows no trace of decomposition. The blocks of fat lime and hydraulic lime are in equally good condition. Some blocks are slightly worn by the mechanical action of the sea.

"*Third series of Blocks.*—Large blocks made on land at the same time as the blocks of the second series, and allowed to dry for nine months before being placed in the sea.

"These blocks were composed in a similar manner, and of similar ingredients to those of the second series.

"Under the influence of this long exposure to the air, these blocks at the end of nine months had attained great hardness and solidity. Their structure was compact, and chips could be struck off with a hammer, as if the blocks had been made of stone. Some of them showed small cracks on the upper surface, owing, it is supposed, to the unequal quality of the fat lime used in their fabrication.

"When exposed to the sea they have all proved good, and are alike in good condition at this date (1867), the fat and hydraulic limes and cement give a similar result.

"*Fourth series of Blocks.*—Blocks made in place at low tide, and immediately covered by the rising tide.

"These blocks, seven in number, were composed as follows :

"Blocks 1, 2, 3, of seven parts of sand, one part of a very hydraulic and silicious lime, and one-half part of cement.

"Block 4, of seven parts of sand, one part of artificial hydraulic lime and one-half part of cement.

"Block 5, of seven parts of sand, one part of hydraulic lime, and one-half part of cement.

"Blocks 6 and 7, of seven parts of sand, one part of common lime and pozzuolana, and one-half part of cement.

"The rocks on which these blocks were constructed are situated at the extremity of the breakwater ; at low tide they are uncovered for an hour or two, and at high tide are covered with water several metres in depth.

"The moulds were made of thin pine boards and established on the rock as a bottom. Their form was a truncated cone of four feet diameter of base, and three feet in height.

"At low tide the moulds were filled with béton and carefully packed. They were immediately covered with the rising tide, and in less than 24 hours the béton was sufficiently hard and firm to allow the moulds to be taken apart and the blocks entirely exposed to the sea.

"Examined at the end of nine months, the four blocks first mentioned were in perfect condition and showed no sign of decomposition. They were very hard and sonorous when struck with a hammer. The 5th block was at first partially decomposed, but immediately hardened.

The 6th and 7th blocks were respectively reduced to one-half and three-fourths of their original size by the destructive action of the sea.

"At this date (1867), the four first-mentioned blocks are in perfect condition, having completely resisted the action of the sea; the fifth block is now as hard and solid as the preceding ones and shows no signs of decay; the sixth and seventh blocks perished in two and a half years, which is attributed to the presence of pozzuolana, which had been added to quicken the taking of the fat lime by rendering it hydraulic.

"Experiments at Marseilles and at Cherbourg.

"Another series of experiments was commenced at Marseilles at a later period. A large number of blocks of béton-coignet, made with numerous varieties of lime and cement, were exposed to the sea on the outer breakwater of the Bassin Napoléon. When last examined in November, 1867, they were in good condition and had not suffered decay; fat and hydraulic limes giving equally good results.

"Lately a number of blocks have been ordered by the navy department for further experiments at Cherbourg.

"Evidently the experiments have not been continued long enough to test fully the relative resisting qualities against the chemical action of sea-water of blocks cemented with common fat lime and blocks cemented with hydraulic lime, since both show, thus far, equal enduring qualities.

"But the results, on the whole, are interesting, and suggest the following conclusions:

"1. Common lime can be substituted for hydraulic lime in béton-coignet, with an equally durable result, provided the blocks are allowed to harden for a few days on land previous to immersion.

"2. Blocks of béton-coignet (sand and hydraulic lime) can be made in direct contact with the sea, provided they be protected by a crib during the time necessary for the taking, say 24 hours. Blocks thus made have proved as durable as those made on shore; while, under similar circumstances of immediate immersion in the sea and 24 hours' protection by a crib, blocks of ordinary concrete (sand, hydraulic lime, and stones), made with the same hydraulic lime, would disappear in a short time.

"3. Blocks of béton-coignet made on land are quite ready for immersion after drying and hardening for three or four days; while blocks of hydraulic concrete usually require from three to six months for drying and hardening.

"To supply the daily demand for these blocks of concrete in the construction of a breakwater, large yards are necessary, which are usually at a distance from the breakwater. They must have space for 1,000 to 2,000 blocks in various stages of fabrication and drying; they require, also, a large establishment of machinery and railways. A large capital is thus invested and the expense is heavy.

"In making béton-coignet, less machinery and plant, less ground for drying, less preparation in advance, are required; the time and capital involved are less, and the whole cost is consequently diminished.

"Mr. Coignet now proposes the construction of piers and breakwaters in the following manner:

"1. Blocks of béton to be made on land, in length equal to the breadth of the pier and of corresponding size, weighing, say, 140 tons, to be lowered into the sea, and placed side by side, across the line of the pier, for foundation.

"2. The wall to be constructed likewise of béton, in place, forming, thus, a single mass, binding the blocks below by the weight and solidity of the wall.

"For this he would use from five to seven parts of sand, one of lime, (fat or slightly hydraulic), and one-fourth to one-half part of cement.

"But it is not probable that the Government engineers consider the experience already gained sufficient to warrant them in recommending so great an outlay at present as this experiment involves."

## Conclusion.

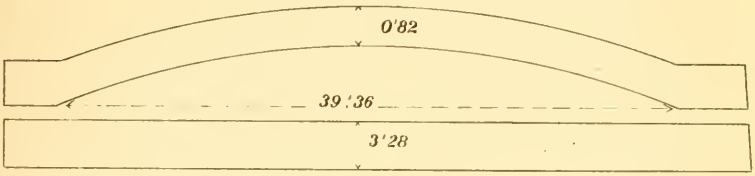
The materials of béton-coignet exist in all countries and in most localities, seldom requiring long and expensive transportation.

Sand is easily excavated, lime is a simple preparation, and both are materials of low cost; most of the labor in making is performed by machinery, and little of the manual labor required need be skilled labor.

Sand, lime, water, machinery, motive force, few tools, and common

labor are the elements of structures made of béton; and the béton itself is well adapted to numerous daily wants, in which solidity, durability, and cheapness are preferable to beauty of materials, the evidence of which is shown in the ground and underground structures of the great Palace of the Exhibition of 1867, and in its increasing application to sewers, tanks, foundations, floors, walls. &c., enumerated in the preceding pages.

*Cost.*—The cost of béton varies with that of the lime and cement employed. In Paris, works in béton cost, including fabrication and construction, from $5 to $8 per cubic yard. Moulded blocks of béton, with ornaments, cost from $8 to $11 per cubic yard. Flagging, 2 inches thick, costs 56 cents per square yard; 5 inches thick, $1.60 per square yard. In very large and massive béton works, such as foundations, &c., the total cost, in Paris, amounts to $3.80 per cubic yard, composed of $2.25 for cost of materials and cost of fabrication, and $1.55 for transportation, excavation, centering, and construction.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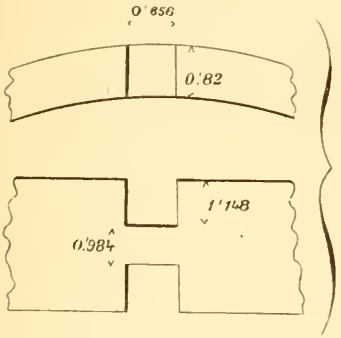
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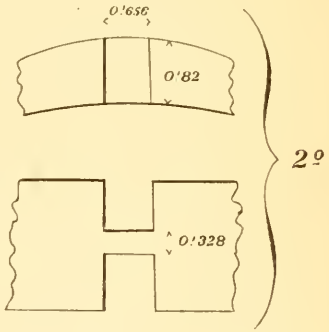
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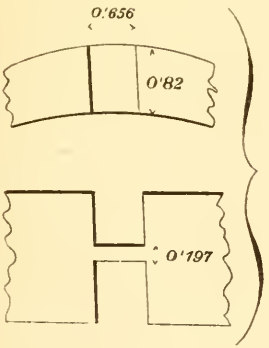
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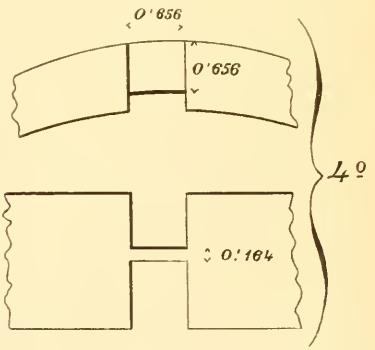
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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## XI.

## NITRO-GLYCERIN—ITS MANUFACTURE AND USE.

A paper read before the Society, June 2, 1869, by Stephen Chester, Civil Engineer, Member of the Society.

It is with some degree of diffidence that I present to the consideration of this Society a paper upon a subject which has been already so ably treated by one of our members. It is with the desire, however, to call attention more particularly to details of the preparation of Nitro-Glycerin, its most expedient application to land or submarine blasting, and to invite a consideration of the means that may be successfully employed to render the use of this valuable agent less obnoxious to public sentiment.

As a preface to the statements to which your attention is invited, a few quotations from the able paper of Mr. North, and from other sources, may be permitted.

*First known as a medicine.*—Nitro-glycerin was discovered in 1846, by Sobrero, and it was first used as a homœopathic medicine, being supposed to be a powerful remedy against nervous headaches. It is true that a minute portion, applied even to the finger will, usually *produce* the most violent and disagreeable headache; and if there be truth in the adage, "*Similia, similibus curantur*," should at times be remedial,

*Applied to blasting.*—The application of this oil to blasting, and its first practical production in large quantities, is attributed to a brother (now deceased) of Alfred Nobel, though the latter patented its application in 1863.

As its name indicates, it is the result of a combination of glycerin with nitric acid; large quantities of sulphuric acid entering into its manufacture, but forming no part of the product.

*Manufacture of described.*—Its manufacture is simple and rapid, and attended with no danger whatever, however powerful and explosive the ultimate product may be.

The apparatus used and the process employed under the patent of Stephen Chester and Otto Bürstinbinder is as follows: Any number of stone jars, each of about four gallons capacity, are placed in a trough of ice-water, in which is also placed a leaden worm, connected on one end to a reservoir of compressed carbonic acid gas, and on the other to a horizontal tube, having projecting tubes closed by stop-cocks opposite to and corresponding with each stone jar. Within each jar, and connected to its corresponding stop-cock, is suspended a perpendicular glass tube, its lower end closed, and having, in several horizontal planes, radial tubular arms of diverse lengths, the ends of which terminate in fine orifices, the axes of which are turned in one direction, tangential to the arcs described by the respective arms, from the perpendicular tube as a centre.

On an overhanging shelf are conveniently placed tin cans with faucets, corresponding to the stone jars, to hold glycerin. A thermometer is suspended within each stone jar.

Supplementary to this apparatus, all of which may be contained in a small wagon, should be several wooden tubs, of capacity to contain from sixty to eighty gallons, and a liberal supply of water.

*Formula of Composition.*—The operation is commenced by placing in each of the stone jars sulphuric and nitric acid, and in the tin cans, glycerin, in the following proportions :

| | | | | | | |
|---|---|---|---|---|---|---|
| Sulphuric acid, having specific gravity | | | | | .....1.84 | —6 pounds. |
| Nitric | " | " | " | " | .....1.45 | —3 " |
| Glycerin | " | " | " | " | .....1.23 | —1 " |

The stop-cocks are partly opened, and the cold carbonic acid gas allowed to pass through the glass apparatus as soon as the acids are introduced.

This is, first, to cool more rapidly the mixture, which immediately becomes quite warm; and, secondly, in order that a mat or superstratum of dry carbonic acid gas may separate the surface of the mixed acid from contact with the moist atmosphere.

*Carbonic acid gas anhydrous and refrigerative.*—The office of the sulphuric acid is, doubtless, that of dessication, to absorb and take up the water produced by the union of part of the hydrogen of the glycerin ($C^6$ $H^5$ $N^3$ $O^{18}$) with part of the oxygen of the nitric acid ($NO^5$). But as sulphuric acid will absorb water from the atmosphere so rapidly as to considerably diminish its specific gravity in a few hours, it is highly important that the "sponge" should not be prematurely saturated.

*Previously mixed acids give poor results.*—And here it may be said that sulphuric acid that has been exposed to the air, or acids mixed, and thus kept in carboys, will *not* produce favorable results.

As soon as the respective thermometers indicate that the mixture has fallen to a temperature of 62° Fahrenheit, the glycerin may be allowed to pour in, and the gas stop-cocks more fully opened.

*Glass apparatus causes to rotate and agitates mixture.*—From the description of the glass tubes before given, it will be apparent that a rotary motion will be given to the mixture, which, together with the violent ebullition of gas bubbles, insures the complete distribution of the glycerin throughout the mixture, while the cooling tendency of the compressed and cold gas counteracts the heat produced by the union of the glycerin and acids.

*Must not get warm.*—The thermometers must be observed, however, and if the temperature should at any time exceed 68°, the flow of glycerin should at once be arrested, until the temperature of the mixture again decreases.

Practically, with a good flow of gas I have allowed the entire contents of a can to flow uninterruptedly, and the thermometer meanwhile did not vary two degrees,

*No danger if it burns.*—Should the temperature of the mixture run above 70°, the glycerin will commence burning. This does not infer danger, however, as the mixture is yet unexplosive, and even the burning will be instantly arrested if a small piece of ice be dropped on the burning surface.

As soon as the proper quantity of glycerin is introduced into each jar, its entire contents are plunged into one of the wooden tubs, previously nearly filled with water, and agitated with a stick.

*Precipitation of result.*—In a few moments nitro-glycerin will precipitate, and the acidulated water may be drawn off from the surface of the nitro-glycerin, fresh water poured on, and thus the contents of several jars may be precipitated in each tub.

*Is now for first time explosive.*—This product is now for the first time *explosive.* But it will be observed that now the operation is *complete,* and the article is ready for use.

*Should not be placed in metal.*—It is *not,* however, ready for packing, nor for transportation. As for that, it needs that every particle of free acid should be removed.

This is, to a degree, accomplished by repeated washings in strong alkaline and pure water. Your particular attention will be hereafter called to this point.

*Average result.*—With proper attention to the above directions, and using good commercial materials, the average result should be one and a half pounds of nitro-glycerin to each pound of glycerin used.

In our own experience, acids of good quality, previously mixed at the manufactory with excellent oil, gave an average of less than one pound of nitro glycerin to each pound of glycerin used.

*Experimental trial.*—The following is the result of a carefully-tried experiment, with a view to estimating the exact value of certain commercial materials :

| | Beaumè. | Spec. grav. | lbs. oz. | | |
|---|---|---|---|---|---|
| Sulphuric acid | 66° | (1.82) | 18 6 | @ 2¾ cents | $0.50 |
| Aquafortis | 45° | (1.44) | 9 1 | @ 15 " | 1.36 |
| Glycerin | 28° | (1.23) | 3 0 | @ 34 " | 1.02 |
| C. A. gas about | | | | | .05 |
| Total cost | | | | | $2.93 |

*Cost.*—The result exceeded five pounds. Hence, the nitro-glycerin cost less than $58\frac{6}{10}$ cents per pound. But the glycerin used cost exorbitantly; equally good can be procured for 20c., and had such been used the net cost would have been only $50\frac{2}{10}$ cents per pound.

Several hundred pounds of the same materials have been used, with similar average results.

*Average cost.*—To the above may be added, to cover cost of labor, transportation of materials, loss by breakage, etc., etc., about 14 cents—making the actual cost of nitro-glycerin, at a point somewhat remote from any depot of materials, about 64 cents per pound.

*Capacity of apparatus.*—The jars above described will conveniently hold about 45 pounds of acids and 5 pounds of glycerin each, giving an average result of 7½ pounds of nitro-glycerin.

*One operator can make.*—One operator can, with ease, attend to ten jars at one time; and, with a liberal supply of carbonic acid gas and cold water, can refill these jars three or four times during the day. With a very inadequate gas generator and reservoir, I have only once had these vessels refilled three times. Hence, one man can readily produce 150, and *may* produce 225 pounds per day. The mere labor, however, of decanting the large amount of acid to produce the larger amount would be very severe for a single man.

*Appearance.*—When first precipitated, the product appears semi-opaque, about the color of cream. It afterwards becomes more transparent, and has a slight straw-color tinge. Its specific gravity is 1.6.

*Peculiarities.*—When poured into water it does not separate, but large globules form as it touches, which instantly unite as they come in contact with each other.

*Produced by explosion.*—I am unable to give the chemical formula for nitro-glycerin, but according to the *London Mechanics' Magazine*, September, 1865, by explosion one volume of nitro-glycerin is converted into

| | | |
|---|---|---|
| Carbonic acid gas | 429 | volumes |
| Steam | 554 | " |
| Oxygen | 39 | " |
| Nitrogen | 236 | " |
| In all | 1,258 | volumes for one volume |

of liquid oil, being thus theoretically five times more expansive than gunpowder.

*Not measure of effective force.*—But this must not be assumed as a measure of the *effective force* of nitro-glycerin as compared with that of gunpowder.

*Powder deflagrates.*—The latter does not properly *explode*, but deflagrates with a greater or less rapidity, dependent upon its ingredients, dryness, and size of grain. Hence its force operates accumulatively, and considerable time is required to develop the full bulk of its expansion.

*Force required to project masses.*—When it is desired to set in motion a mass, as for instance the projection of a ball from a large gun, this force, which commences with a slight expansion due to the deflagration of the surface of a few grains, and rapidly accumulates, as the ball—its inertia being overcome—moves forward with increasing rapidity, is admirably adapted to the exigencies of the case.

*Force required to disrupt.*—But when complete disruption of all the surrounding parts is desired, it must be at once evident that it is a great defect that powder is *not* more rapid in its action.

In many instances, the rock beginning to move, permits much of the gas to escape, without producing the full effect due to the expansion produced. Secondly, it is a well known fact, that where large quantities of powder are fired, combustion is seldom entire, much of the powder being thrown out unburned.

*Nitro-Glycerin percussive.*—The combustion or explosion of nitro-glycerin is supposed to be *instant*. Practically it is so, and the effectiveness of its disrupting force is in great measure due to the fact that its maximum of expansion *instantly* acts upon the confining walls with percussive force.

*Illustration of Percussiveness.*—In one instance where a five-pound charge was placed somewhat indiscreetly, in a rock cut on the Boston, Hartford and Erie Railroad, the rock thrown off was entirely shattered; but in the immediate locality where the charge had been, several bushels of impalpable white powder were found; evidently the rock, crushed and calcined by this tremendous force.

*Breaking effect under water.*—Five pounds placed in a stone jar, and suspended against the iron side of the steamer Scotland, sunken off Sandy Hook, cut, as with a knife, a fissure ten or twelve feet in length.

It is believed that an equivalent amount of powder, similarly placed, would have rocked or swayed the whole side, but would not have *cut* it; first, because its action would not have been *percussive;* and next, because its initial, or rather resultant force would have been spread over a larger area than would that of the equivalent of nitro-glycerin, the less bulky material.

*Percussiveness not always desirable.*—But it is highly probable that the "percussiveness" of nitro-glycerin—if that term may be allowed—is, to some degree, a disadvantage, when not used with discretion, as it is obvious that in many instances a degree of elasticity is desirable to produce the best effects, and to move the largest amount of rock.

*Column of atmospheric point of reaction.*—Again, as a sequence of the *instant* combustion of nitro-glycerin, its expansion reacts from a *fixed resistance* other than what is met by the more slowly-consuming gunpowder.

The atmosphere, moving at a velocity of one hundred miles per hour, overthrows houses and trees, and bears off heavy masses. With a velocity of one thousand miles per hour, nothing could resist its force.

If it could be conceived that an iron ball should be projected through space with the velocity of hundreds of miles per second, and should, with that velocity, strike against a wall of air of the usual density,

would it not as surely be dashed to atoms as would a ball of glass upon a wall of adamant ?

*Atmosphere resists instant movement.*—It is obvious that to *sudden movement* the air opposes as fixed a resistance as inelastic water, only in less degree, as its particles move more freely among each other, and a corresponding degree of velocity is required to develop that resistance.

*What is line of least resistance?*—Hence, to the expansion of nitro-glycerin, the *line of the least resistance* is not that apparent, but one modified by the pressure of the superincumbent column of air, which is only less than a fixed resistance, as the expansion of nitro-glycerin is less than *instant.*

A charge exploded upon the face of a rock, in the open air, will shatter the rock beneath it.

*Illustrations.*—A few years since, a small quantity exploded upon the pavement in Greenwich street, New York. It will probably be recollected that the pavement was torn in pieces, and quite a pit excavated beneath.

If a charge be placed in the bottom of a twelve or fourteen feet hole, and this be covered with sand to within three or four feet of the top, and then another charge be placed above the sand, and *no* covering above it, the explosion of the upper charge will cause the lower one also to explode—both with effect.

*How Nitro-Glycerin breaks rock.*—It is universally known that while in powder-blasts the break usually occurs near the centre of gravity of the charge, in nitro-glycerin explosions the break is at or below the bottom of the hole, extending outward and *downward.*

Other corroboratory instances can be quoted, but the fact is too obvious to require them.

*Nitro-Glycerin not easily caused to explode.*—Nitro-glycerin, when newly made, or *free from other elements,* is not easily caused to explode.

Heat will not explode it, unless the nitro-glycerin reaches a temperature of 360°. A small mass of iron, at white heat, and dropped into nitro-glycerin, would not be *liable* to cause explosion, since, the specific

heat of the article being great, the heat from the piece of iron would be rapidly disseminated, and no portion of the oil reach 360° before the iron had lost its heat.

Sparks of fire or scintillations from hammered iron, are instantly extinguished.

A very heavy blow from a hammer upon oil placed upon an anvil is required to make it detonate; and then, as with gun-cotton, only that explodes which is actually crushed between the impinging points of iron, the rest being driven away.

It is not probable that any amount of concussion, short of that produced by contiguous explosion, when developed heat probably assists, will cause it to explode.

*Illustrations in use of new oil.*—On the B. H. and E. R. R., a charge was placed in a hole; a small wad above it, on which was placed a pound or two of powder, to which fire was communicated by a common fuse.

The hole was carelessly filled with loose earth or sand.

The explosion of the powder blew out the dirt, but did not cause the oil to explode. Shortly after, the oil commenced burning, and seemed to be entirely consumed, no subsequent explosion taking place.

In another instance, similar to the above, the oil did finally explode; but it is probable that it became heated to above 360°.

*What is required to cause it to explode.*—In practice, the confined explosion of ten grains of fulminate of mercury, or of its equivalent of gunpowder, is required to explode it with certainty. Properly confined, so as to cause the flash to penetrate the body of the oil, this charge will rarely, if ever, fail to produce the called-for effect.

*Means used to fire blasts.*—The means of firing blasts may properly be considered in connection with this subject.

*Common fuse cartridge.*—In ordinary railroad or land blasting, contractors or laborers are not easily persuaded to abandon the ordinary *fuse*, for electricity, with its accompanying inconveniences of application. A small cylinder of paper, containing, perhaps, a half ounce of powder, securely tied around the lower end of the fuse, and also closed

at the lower end, the whole, when prepared, being dipped in melted paraffine, makes a cartridge which rarely, if ever, fails under any circumstances, and can always be readily constructed.

*Electricity must sometimes be used.*—But there are circumstances under which the aid of electricity is indispensable.

First. When a simultaneous line of blasts may be required; and next, in all submarine operations.

*Three kinds of electricity.*—There are three distinct methods of applying electricity, or it may be conventionally said that three *kinds* of electricity are used, involving three kinds of apparatus for its production, and corresponding means of application.

*Kinds of electricity.*—These may be classified as follows: *Static electricity*, or that produced by frictional machines and analogous to atmospheric electricity. Second, *Magneto-electricity*. And third, *Galvanic electricity*.

*Static most popular.*—The first seems at present to be the most popular, on account of the apparent simplicity and ease of application.

*Static apparatus.*—The apparatus used for the production of the spark is in principle an electrophorus, with a condenser to collect and discharge at once a series of accumulated sparks.

*Where and by whom made.*—They are manufactured by Smith, in Boston, and by the Messrs. Chester, of New York. The machine produced by the latter gentlemen is externally a cylinder of ebonite, about 9 inches long and 4½ in diameter. On one of its closed ends a small crank and trigger, and on the other the two binding screws to which to connect the wires. Its capacity is to throw a large spark of one and one-half inches in length, and would doubtless fire sixty or seventy cartridges simultaneously.

*Fulminate fuses.*—But this spark will not fire powder, but will fire a mixture of oxygen and hydrogen gas, or certain sensitive fulminates. The caps or cartridges prepared for this kind of electricity contain—first, a minute quantity of very sensitive fulminate as "priming," and a larger quantity (for N. G. at least 10 grs.) of less sensitive fulminate as load, or exploder.

.The recipés for their preparation are innumerable, and need not be entered into here.

*Fulminate fuses made by.*—The preparation of them, however, has become an extensive business, and I know of three firms that manufacture them extensively—viz., Mr. Mobray, and Mr. Smith, of Boston, and Mr. Bishop, of New York. I need hardly say that they have been extensively manufactured and used on the continent and in England, and are not the result of Yankee invention.

*Description of fulminate fuse.*—In this country the sensitive fulminate is rubbed upon the flat opposing faces of two discs of lead, to the other sides of which are attached the terminal wires which first pass through a small cylindrical block of wood. The exploding charge is usually contained in a copper cap, into which the wooden block is inserted.

*Objections to use of fulminates.*—Though so very popular, it may very properly be suggested that many grave objections present themselves to our consideration against the use of this form of electricity, and that engineers ought to discourage it.

First. On the ground of expediency. Of course, it is obvious that this machine can *only* be applied to the explosion of cartridges carefully prepared in a laboratory, and if a contractor, by chance, gets out of cartridges in an out-of-the-way place, there is no makeshift or expedient to which he may temporarily resort.

Secondly. It is not practically reliable. The "tension" of static electricity is so great, while the "volume" is so small, that it is very difficult to confine it to ordinary conductors.

*Static electricity not easily insulated.*—Hence the complete insulation of these conductors is difficult to obtain, especially in the hurry and reckless haste that naturally grows up on all public works. Even if the insulation of the wires be of the best; if at any point between the batting and the cartridge the wires are contiguous, or touch any damp surface, the tendency of the spark is to pierce the insulation and travel over the damp surface.

Of course, these difficulties are very much increased in submarine

blasting. But the third, and most important objection to the use of the fulminate cartridges arises from the danger arising from their use.

*Sensitiveness of fulminate cartridges.*—On a cold, dry day, I have exploded them by touching the end of one wire, the other end lying on the ground.

*Danger of fulminate cartridges.*—But even if less sensitive than that, it must be remembered that the "torpedo" must, in submarine blasting, be previously prepared, and must *contain* this cartridge. The diver who places the torpedo is swayed about by the tide, and it is subject to violent concussions, which, though inadequate to cause the nitro-glycerin itself to explode, yet may well cause the fulminate to do so; but, lastly, in paying out the wires, there is a great tendency to cause the surfaces of the two leads to rub together; which friction, if it does not cause a premature explosion, at least rubs the fulminate from part of the surface, bringing the leads into metallic contact, and thus causing a failure.

*Examples of danger from fulminates.*—Mr. Mobray narrowly escaped losing his life, in attempting to draw one of these cartridges from a loaded hole.

Last winter, a frightful accident occurred near Sandy Hock, resulting, without doubt, from the use of these cartridges.

*Precautions to be taken.*—But if used at all, let them only be used on land, where the cartridge may be lowered into the hole; after the latter is loaded, never let it be placed in the cartridge of nitro-glycerin before placing it in the hole; and if it fails to explode, never withdraw it, but, cutting the wires above, attach them to another cartridge, leaving the first where it is.

*Cost of fulminate cartridges.*—The best I have used are those made by Smith, of Boston, and cost, I believe, ten cents each.

*Magneto-electricity.*—The magneto machine is of a more expensive character. The electricity is produced by rapidly revolving an armature of soft iron, covered with a helix of fine insulated wire, between the poles of a number of permanent magnets. As this revolving armature changes polarity with each revolution, a charge of inductive electricity flashes through the wire forming the helix.

*"Tension" of current less than Static.*—The character of this electricity is a modification between static and galvanic. Its "tension," infinitely greater than that of the galvanic current, is, nevertheless, very much less than that of static electricity. Hence, it does not *jump*, but will follow a relatively poor conductor.

*Beardsley's cartridge.*—Mr. Beardsley has taken advantage of this in the production of a very ingenious and excellent cartridge. The terminal wires (No. 16 copper) pass through a cylindrical block of wood, about three-quarters of an inch long, and one-quarter inch diameter The terminals are less than one-eighth inch distant, and, with a triangular file, a small V-shaped groove is cut through the wood and the ends of the wires. A strong lead pencil mark is made to connect the wires. This is sufficient to make continuity of current; but the conductor being *bad* it becomes so heated during the passage of the current as to ignite gunpowder, and even burn the wood.

A mere wrapper of paper, enveloping the cylinder of wood and projecting beyond, when filled with powder, and its end being closed, and the whole rendered impervious to water, completes the cartridge.

*Results good, but machine expensive.*—With this machine, insulation is much more easily attained, and the element of danger is avoided.

It is, however, expensive, cumbersome, and easily gets out of order.

Galvanic electricity and its production are too well understood to require any explanation.

Of course, explosion depends upon the heating of the fine platina wire connecting the two terminals.

*Galvanic cartridges.*—So little "tension" has the current required to perform this office, that *bare wires* may be used even in submarine blasting. It is always expedient, however, to use well insulated wires. This is the oldest of all plans for using electricity in blasting, seems the most reliable, and the safest under all circumstances.

*Cost of cartridges.*—No improvements have been, nor can be made in its application, except in the compactness and durability of the batting used, and in the convenient form and cheapness of the cartridges; and I have again to mention the Messrs Chester as

having produced a very compact batting of great endurance, that can be carried from place to place for weeks without recharging, and in making cartridges which can be procured for about 10 cents each. This batting may be charged and remain thus inactive for six months, and then be brought into action as active as when first charged.

*Application of N. G. to blasting.*—I appproach the question of the most expedient application of nitro-glycerin, and the economy of its use with that of gunpowder, with much hesitation, since the testimony of the various contractors and experts whom I have consulted is so diverse, and so conflicting, that I am compelled to depend upon my own observations, which have been limited.

So far as I have any experience, however, I have, for my own guidance at least, concluded that the following general rules should be observed :

First. That to produce the best effects, though nitro-glycerin should be allowed a certain chamber in which to first expand, to give some *degree* of elasticity, so as to modify its percussive force, yet the limit of its expansion should be *absolutely* confined.

It is certain that the gas forms quickly, and readily percolates through sand. It is obvious that it *must* do so, from the fact, heretofore quoted, that a charge near the top of a hole filled with sand *instantly* explodes a charge at the bttom. The intensely hot gas percolates through the sand.

*Seam blasts.*—Again, nitro-glycerin has been tried in seam blasts, but the results were very unsatisfactory, not seeming to nearly equal powder. It is probable that in the larger fissure of a seam blast filled with sand a large quantity of the gas escapes.

*Mixture of nitro-glycerin and powder.*—In Europe, charges of powder moistened with nitro-glycerin are used in seam blasts, it is said, with excellent effect. I have not yet had the opportunity of verifying this by actual experiment.

*Must be confined.*—An air-tight tamping is desirable; or a block of wood, nearly filling the hole, may, with advantage, be placed on the top of the oil.

*Should be used in cartridges.*—Secondly, it is not practically safe to pour the oil into a hole, as it is so seldom that holes of any depth are, for their whole depth, water-tight.

*Danger from holes leaking.*—Besides the danger of losing part of the charge, the escape of any oil that may trickle through an aperture to some distant basin, is a source of future danger. At least one serious accident has occurred from this cause.

*Cartridges employed.*—Cartridges of tin, rubber bags, paper cylinders soaked in paraffine, and animals' entrails, have been successfully employed.

*To be distributed.*—Third. I am of the opinion that the charge may frequently be distributed to great advantage, and except for the purpose of securing more tamping, and consequent confinement, it is not desirable that the charge should be in one mass at the bottom of the hole, but better in several cartridges, at various points of the hole.

*Cost of nitro-glycerin and powder.*—Nitro-glycerin costs contractors through the country an average of $1.60 per pound. Five pounds of powder cost about 80 cents.

*Apparent economy of use.*—Hence, if one pound of nitro-glycerin represents the effective force of but five pounds of powder, and the labor of using either be the same, it is obvious that powder is much more economical than nitro-glycerin. In fact, many who have used both declare in favor of powder. With due deference to their much larger experience, I cannot but believe that their judgment has been based upon an indiscreet, not to say irrational, use of the oil. It is, of course, almost impossible to establish, except by long and judicious experience, the exact relative effectiveness of the two, but it does not seem too much to announce that one pound of oil, properly used, may represent seven pounds of powder. But allowing that one pound of oil represents but five pounds of powder—

*Real economy in using N. G.*—1st. The labor in preparing for one volume of oil certainly need not be one-third as great as in preparing for the equivalent of powder.

2d. It is conceded that it shatters and breaks up rock, when powder overthrows large masses, which require subsequent additional labor and blasting to reduce to transportable dimensions.

3d. It breaks at or below the bottom of the hole, shattering downward or outward. The natural deductions need hardly be followed to their logical conclusions.

*Why N. G. has not been universally adopted.*—But nitro-glycerin certainly has not hitherto been generally adopted for blasting purposes in the United States. The principal obstacles opposing its more general use have, doubtless, been the following, to which I particularly invite your attention:

*Difficulty of obtaining it.*—First. The cost, and the extreme difficulty of obtaining the article in quantities sufficient for experimental purposes.

*Danger of storing.*—Second. Being generally necessary to purchase it in large bulk, it is required to store it in the vicinity of the locality where used—when it either deteriorates, or becomes excessively dangerous to handle.

*Popular prejudices.*—Third. Public sentiment almost forbids its transportation by any ordinary route of travel, and its storage near human habitations or routes of possible travel. Popularly, it is regarded as a material excessively sensitive—liable to explode with the slightest shock, or even to explode spontaneously, or from mere change of temperature.

*Has been misused.*—Fourth. It has been recklessly condemned by ignorant contractors after a very limited use of the oil, in a very irrational manner.

To these objections I would respectfully suggest that a careful consideration of the care, cost, and safety of its production, as before described, may naturally lead to the conclusion that most of these obstacles may be relieved.

*Can be produced cheaply.*—To the first and second objections, it may be stated that, when more generally adopted, it can be produced at a cost not to exceed the cost of the nominal equivalent of gunpowder,

and the outlay required to prepare for its manufacture would be very inconsiderable when any amount may be required.

*New oil much better than old.*—I have made the statement that nitro-glycerin, when long stored, *deteriorates*. My authority for this statement is in the fact, that many pounds of oil, recently produced by the process described, and many pounds of oil obtained elsewhere, and long stored, have been used, under precisely similar circumstances, on the Boston, Hartford and Erie Railroad, and in every case the effect produced by the first-mentioned oil has been astonishingly greater than that produced by the latter.

The inference is unavoidable: either nitro-glycerin deteriorates greatly when long stored in metal vessels, *or* the blasting oil sold by a well-known company is not the nitro-glycerin produced by the process described, and does not possess its qualities.

*Prejudices not unfounded.*—The unfortunate popular prejudices regarding this material are not unfounded. Notwithstanding its limited use in this country, already many terrible accidents have attested to its fearful power. While these may in part be attributed to gross recklessness in its treatment, they still seem to indicate that the material possesses a degree of sensitiveness not consistent with the statements hereinbefore made.

I believe I am right, however, in stating that every accident that has yet occurred, has been with oil that had been long packed in tin vessels.

*Why old oil is dangerous.*—Chemical experts have conceded that nitro-glycerin can, and does, decompose; but I am not aware that any one has satisfactorily determined what the result of such decomposition may be. Mr Mobray, an accomplished chemist, and extensive manufacturer of nitro-glycerin, declares that it does *not* decompose, *provided* that every particle of free acid be removed from it.

*Cannot be made free from acid.*—But this I believe to be nearly, or quite impossible. Minute globules of acid become enveloped in larger globules of oil of the same specific gravity, and owing to their peculiar cohesiveness, before described, there is no certainty that all these globules come in contact with the water in which the oil is washed.

We have placed oil already repeatedly washed in a vessel containing a strong alkaline solution, and it was frequently stirred therein. For a day or two, the water did not lose its alkaline character, but after several days it became decidedly acid.

*Tin vessels dangerous.*—Hence, when placed in tin vessels, what acid thus exists may be locked up in the centre of the mass, but by slow movement particles may, at length, come in contact with the metal. If no other decomposition occurs, may not the bubbles of mixed hydrogen and oxygen gas, and perhaps nitrous acid gas, that may be formed, be a sufficient cause for the extreme sensitiveness to explosion being then developed? At all events, whatever may be the cause, it is quite certain that under these circumstances, something is frequently produced which, however minute in quantity, is all-sufficient to produce dire results.

*Should never be transported.*—This being undeniable, I would respectfully submit to your judgment that popular sentiment need not be outraged by the transportation of this material; life need not be risked by its storage in large quantities, since it can nearly always be easily and cheaply manufactured in the immediate vicinity of the locality where it is to be used.

It is to be remembered, also, that there are reasons for believing that the *value* of the material thus newly produced *may* be greater than that of oil that has been stored.

The process of manufacture is so simple, the formulæ so few and arbitrary, that a chemical expert is not required, but any reliable and intelligent laborer may be instructed in one day to manufacture it successfully.

To the fourth objection it may be said, that, though unfortunate that ignorant experiment may, in its results, lead us to false conclusions, yet all popular improvements pass through similar ordeals. There seems to be no cure to the prejudices thus created, except in the fact that it will eventually be submitted to the experimentation of more intelligent and more careful men, who will, at least, develop its greater value, or give us more reliable data upon which to determine its value as compared to powder or other explosives.

XII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## Address of JOHN B. JERVIS, Hon. Member of the Society, delivered at its First Annual Convention, held June 16, 1869.

Mr. PRESIDENT AND GENTLEMEN:

I thank you for the honor you have bestowed in making me an honorary member of your Society. Perhaps you may not expect me to say more at this time, but it has appeared to me a fitting occasion for some remarks on matters connected with the prosperity of your Society; and, if I may trespass on your time, I will occupy it to briefly discuss a few points on this subject.

It does not appear worth while to speak of the general character and importance of the profession, for that has recently been so ably done by your President that I could hardly add to what has been done. I will, therefore, content myself, and hope you will excuse me, with the more common-place affairs that affect the interest of your Society.

All professions must have a beginning. There must be preparation, just as when a fabric is to be reared, the rubbish must first be removed and a proper foundation prepared on which the structure is to rest. You will suspect, from this, I am going to talk to the beginner, rather than to those who have a matured skill and experience.

A civil engineer I understand to be a man who devises and executes

works, as canals, railroads, water-works, bridges, mining, etc. I regard it as different from the strictly mechanical engineer; but the civil engineer should know much of mechanical engineering, though he be not a professor in devising and constructing machinery.

After a fair education in the ordinary elements, the young man that designs to prepare for the profession of an engineer should study mathematics so far as to qualify him to make any computation of quantities, and to carry forward any investigations that he may find it necessary to make in pursuing the science of mechanical philosophy, and especially in regard to the strength of all materials that may be required in the structures he may be called upon to erect, and the capacity of his structures to support the object for which they may be designed.

The engineer, having got thus far in his study, he is prepared to enter on the study of mechanical philosophy. In this branch he will hardly be able to learn too much. It enters deeply into the affairs of an engineer. In this, especial attention should be paid to the character of all the materials required in the varied structures it is his business to provide for, and the form and position of materials best adapted to the end it is sought to secure.

The next object I should propose for study is hydraulics. This enters into nearly all the questions in engineering, especially canals, water-works, mining, and bridges. In some respects it is a difficult science, not in its mathematic or theoretic aspect, but in the difficulty of obtaining accurate data on which to rest the computations for specific objects. This difficulty only renders its careful study more important, and it will be found that much has been reduced to a scientific form, and if not in all cases exact, is so close an approximation as to afford a reasonably safe guide in practical hydraulics.

I have not noticed the surveying feature, for, with a proper knowledge of mathematics, it is only necessary to learn the use of instruments in order to establish lines and levels. The education, thus far, may be obtained at any school that has a good mathematical department.

The next step in education should be the study of structures of various kinds that have been erected by experienced engineers. These have been published in various books, and may be advantageously studied without a professed teacher. So far, the student is merely a student, and is only well prepared to enter on the practical or real study of his profession.

Every work detailed and set forth in books has been erected with some specific object, and under circumstances that are not likely to be in all respects found again for any similar work. The young engineer will, there-

fore, require great care in recommending a structure he has examined in a book, to see that the circumstances surrounding his case are analogous to the original. Neglect, in this respect, may lead to very unfavorable results. With a sound knowledge of principles in regard to form of structure best calculated to secure the object for which the work is designed, and to afford the necessary stability and permanence, and of the materials best adapted to this purpose, he will be able to make an intelligent criticism on what he examines, and judge how far it may be a guide in his operations.

The next step in this training is to enter on the field of practical duties under the guide of an experienced engineer. In this situation he will have opportunity to examine the unbroken ground, learn the reasons for the various parts of the work, and why it may be proper to depart from the order of some similar work he may have noticed in his studies. Here he will see the ground to be occupied, and, by communion with his principal, will see how far it may be adapted to the proposed work—the various needs of the structure, the facilities for materials most suitable, and how far a modification in plan and materials may be required to meet the circumstances that may exist. It will be a practical question to determine to what extent the expenses may go. In some works, absolute stability and permanence are of high importance, especially if great inconvenience will arise in making repairs and renewals. The foundations, however, of any work, should be stable, well adapted to support the weight of superstructure, and of permanent materials. This is a part that can rarely be renewed without taking down the whole fabric, and the engineer should be especially careful in this respect. It should not be secured by unnecessary expense, as this would be a waste of means; but the engineer will be justified in doing something more than may appear necessary rather than to fall below safety. If the foundation is exposed to surf or running water, especial care should be taken to guard against this action, or it may undermine the best work. This part of a structure will often be expensive, and the engineer who looks for eminence in his profession, must study this branch thoroughly. It will not do for him to make his foundations inadequate, nor will he be justified in incurring unwarrantable expense; what he wants is enough for security, and his skill is to obtain that and such excess as will provide for such contingency as may possibly happen. Many small structures may fail and be rebuilt without serious damage; but large works, that provide for the current and especially the daily wants of society, should have every reasonable protection against failure. The reason for this is obvious. Therefore, look carefully to your foundations.

Hitherto it has been customary to use timber to a large extent in engineering works. No doubt this has been wise in many cases. It sometimes happens that the surface of a bridge cannot be elevated so as to admit a stone arch, and some substance must be used that will occupy less room, as timber or iron; and if iron be dear and timber cheap, the latter may properly be adopted for a time, until the cost of each approximates; and if the foundations and walls are properly made, the iron may be put on at a future day. Again, a work may be constructed where stone is very scarce or does not exist within the reach of the work at reasonable expense, while timber may be convenient. In this case timber should be used, and if the improvement be a railway, it will, when put in operation, afford the means of transporting stone for the work. In the latter case the timber structure should be so arranged as to admit the stone work to be put in without disturbing the regular use of the bridge. I have known cases where a timber culvert was put down and covered over by an embankment; sometimes they were supposed to be submerged, and so protected from decay, but did not get low enough for safety, and required, in a few years, to be dug out at heavy expense to substitute stone work. The best method in such cases is, to cross so much of the valley as is necessary for the culvert or bridge by a substantial trestle work, embracing as much more as will provide for the end slopes of the embankment. In this way the temporary use of timber may be a decided economy, while the plans will look to an ultimate substitution of permanent materials.

The railway is now the great item of work for the engineer. There has been, and still continues to be, a want of engineering skill and experience in this branch of work. In regard to railway bridges, I am fully of the opinion that stone arches, when a durable stone can be had, is the best style of work for all streams where there is sufficient height for the arch below the grade line of the railway. When this is not the case, the abutments and piers should be of stone, with a view of ultimately putting on a super-structure of iron, when the relative price of timber and iron no longer makes timber profitable. In computing the economy of timber as compared with iron, the danger of fire is to be considered.

The style of engineering structures should have especial reference to adaptation to the object that is to be secured. In this, due proportion should be considered, that the mind of the observer may notice the reasons for the different parts. This demands symmetry, and gives substantial beauty to very plain work. There are situations when it is warrantable to expend some money for mere ornamentation; as in very important works that are much

exposed to observation; but for the most part, the only ornament should be found in the well-arranged proportions of the structure, and this is very great. In this, care is to be taken that no part of the structure has a redundancy of materials so placed as to be a tax rather than a support to the fabric. Also, that the material be placed in the most favorable form to secure strength.

Materials will, of course, have different offices to perform. Some will be exposed to a crushing weight—others to a tensile strain, and others to transverse fractures. In all these cases the strength must be duly considered, and also, the form of material that will secure its greatest strength for its peculiar load.

No skill in forming lines and levels, and in devising structures, will complete the education of an engineer without an intelligent capacity for conducting business. This is an important item in his education, and indispensable to a successful practice. The training of his mind should make this an easy acquisition. He will often find it necessary, for his own investigations, to make written statements and tabulations, which will call into action his skill in arrangement—even his common note-book will exercise his powers to put his work in an intelligible and convenient form. If he keep in mind that he should be prepared to protect himself against forgetting his own work, and be able, at any time, to give an account of his doings, he will feel the necessity of order and ready reference, which are the essential elements of business. Some people suppose an engineer, as a matter of course, knows nothing about business management. An absurd mistake. No profession more needs thorough business qualification. It is still a further error to suppose an engineer, by his education, is unfitted for systematic business. The fact is the very reverse. His education peculiarly qualifies him for a systematic management of business, and his professional duties demand the most varied knowledge in this respect. The first operation in his business life is to set forth, in intelligent form, the work he has been doing; a line, a level, or a series of computations to be set forth in order. Then he comes to prepare contracts and specifications for work, which demands an accurate knowledge of all he wants done, set forth in items so described that there will be no misunderstanding; an important business matter. His work now under contract, he must measure and compute all items of work, and these must be so arranged, in a suitable book, that they can be referred to, and made the basis of his occasional and final statements of work done. So far I have only treated of that branch of a business education that relates to the method of preparing tables, accounts and statements.

But, says one, they know nothing about double entry. It is true they do not usually have much to do with what is called double entry in accounts; but I have known an engineer that suddenly found himself called upon to keep accounts in that way, and he very soon opened a set of accounts, and found no difficulty in keeping them; and, I venture to say, any intelligent engineer would do the same. The most important feature in business is still to be considered, namely, a knowledge of men and of the value of work. I know of no occupation that better qualifies a man in this respect than engineering. He has to deal with men who, as a class, are proverbially sharp in the conduct of their affairs, with whom many questions arise that are not to be determined by a simple computation, and even computations will be questioned. With these men the engineer holds a delicate relation, as the umpire between the contracting parties; and will often be placed between plausible claims on one hand, and a sense of duty on the other. In these circumstances he will have great opportunity to obtain a business knowledge of men. Some he will find upright, though they may have mistaken views of their rights; and others he will find under much pretension to seek what they should not have. Under various conflicts the engineer must aim to do justice between the parties. They have committed to him the duty of adjusting all questions, and in this he must examine the bearing of all claims, and though he may be annoyed at what he thinks an unjust demand, he is in duty bound to render equity, according to the terms of the contract. The engineer being in the employ of one of the parties, it is indispensable that he maintain the reputation of an upright man, for on this the contractor must depend. If he shows a disposition to take undue advantage, not warranted by the terms and spirit of the contract, the contractor will lose confidence if this is against him, and, if in his favor, the other party will be dissatisfied. In all such cases, committed to the judgment of the engineer, he will need the best experience as a business man, and especially to cultivate the golden rule of doing as he would be done by. It is always prudent for an engineer to so prepare his specifications of work that no misunderstanding may arise. But this cannot always be done, as contingent work is sometimes, and I may say often, required.

Pardon me for dwelling a little longer on this point. I will suppose a work is projected, say a railway, and that so much is known of the situation that the work is regarded practicable, and the belief of the projectors is, that it will remunerate the outlay supposed to be necessary. But these have not sufficient funds, and the general opinion is in doubt, and with only an investment interest, the capitalist does not regard it safe. The projectors think

that if they can raise half the cost, or, perhaps, one-third, they can obtain the balance on mortgage bonds. The people interested in the proposed railway have a large indirect interest, and are ready to take the stock on this basis. But they will aim to take as small an amount as possible, and hence the plan of raising the funds on Town and County bonds, so as to lay the burden more uniformly on all parties having this indirect interest. In this way so much is raised as is regarded necessary to commence work. This must be expended before there is a basis for bonds, and before it can be known how much may be depended on from bonds. In this state of affairs the engineer is set at work. He knows there is not sufficient funds provided to complete the work, and it is necessary for him to keep this in view. If the railway is of considerable length, say one hundred miles or over, and he has funds sufficient to build half of it, or fifty miles, before resorting to bonds, his best course will be to put this section into running order, and commence his traffic. This will have two advantages. First, the bonds will be more readily taken on a railway with an active traffic, affording income to pay interest, than on an unfinished line of double the length, with the same amount of expenditure. But the funds have been raised from the whole length of railway, and in each town and county they will want their funds expended in their own district. The latter method has sometimes totally defeated the project, after an expenditure that should have put an available section in running order, and would have secured the ultimate completion of the whole. The capacity, the reputation and the business firmness of the engineer will have much to do in adjusting such a state of affairs.

The business capacity of the engineer will, in most cases, be tried in his intercourse with the managers of the enterprise. In the utmost good feeling they will be very apprehensive of expense, and desire various methods of reduction, which will appear plausible to them, as well adapted to their circumstances. The engineer, very naturally, desires to make a work that will be creditable to his profession. But he must listen respectfully to the suggestions of his principals, and, so far as he can, modify his plans to meet them. The engineer may be well satisfied his plans are best adapted to the permanent interest of the enterprise, and, so far as he is able, should convince the managers they are so. In this he will find need of all his business tact, to yield when circumstances, and especially the want of funds, afford a reasonable apology, or even a necessity, for so doing. It may not, in fact, be practicable to make his work as permanent or complete as its true interest requires, for want of funds, or for want of the most suitable materials. Of these he must exercise his discretion as a business man, as well as a skillful

engineer. There is another point in this connection that will often be more trying than the above. The managers of such enterprises have been known to conduct their affairs with a view to make them subservient to their private interest or ambition. They may do this more or less, without interference with the duties of the engineer, in which case he may know nothing of it, or, if does know, he may not be bound as a duty to take notice of it. But it is very likely to come in conflict, and he will be expected to shape his professional duties in a way that will promote private interests at the expense of the institution. Great skill and adroitness will be practised, and if the engineer has any weak side it will surely be found. These things will always be done under profession of serving the institution. To avoid wrong-doing, and, at the same time, give no just offence under the circumstances, will surely try the business capacity of an engineer. The matter in issue may bring a crisis that will compel resignation.

In review of the brief discussion I have given, I think I am fully warranted in the opinion, that the training and practice of an engineer should make him peculiarly eminent as a business man, not less than skilled in designing and erecting works in his profession.

As the country increases in population and wealth, there will be increased demand for works of difficulty. The growing wants of society, and the benefits that have resulted from improvements already in successful operation, will induce the undertaking of similar works under greater difficulties, and, also, such other kinds of work as had not been regarded practicable in former times. Old works will require enlargement and improvement to meet the increasing demands of public use. I, therefore, see no stopping place for the engineer. He will be called upon to put forth all his powers, and sometimes his discretion, to meet the demands that will most probably be made on his professional skill. As he goes forward beyond his own experience, he will need to understand well the principles that underlie his profession, and how far his own experience, that may be more or less analogous to the proposition in view, will sustain him in whatever he may advocate.

I need not make apology for the preceding remarks; the progressive advance in engineering works in this country shows that the science has steadily advanced. It certainly began very low, and has attained to a very respectable position, as is evidenced by the very creditable and highly useful works that have been constructed, and the improvement that has been made on works erected in the early part of our history.

Fifty years ago, it was generally considered that the land surveyor had

the basis of the engineer's art. To run lines and levels, and map the same, with topography of country, was held in high estimation as an art. At that time little was known of designing plans, and maturing the numerous details of works in engineering. Little had then been done in this country, and, of course, very few specimens were offered for study. To illustrate this, I will tell a short story. In 1826, I made the journey from New York to Boston to study the Quincy Railway. The work was about three miles long. It was made of timber rails, capped with iron plates, ¼ inch thick and 3 inches wide. The cars were high, to provide for slinging the large granite blocks under the frame. The wheels were about 6 feet diameter, made of wooden spokes and felloes, banded in the common wagon method with iron, and the flange was a ring of wrought iron, ¼ inch thick, bolted to the felloes. I spent about one week in this enterprise, to learn what I could of the method of building railways. My young friends will hardly understand what I expected to learn, and, perhaps, think it was very stupid to devote so much time on such an object. But I never regretted the time that I gave to this early specimen of the American railways. I will now mention another instance of the progressive art of engineering. Many years since the British Government desired a bridge over the Strait at Menai, to accommodate the Hollyhead Turnpike Road. They called for engineers to present plans of bridge, requiring a span of five hundred feet. Very few had the boldness to present a plan, and though the celebrated Renney did submit a plan, he spoke in his report so timorously of its success, that the Government did not think proper to engage. Some time elapsed, the Government still soliciting plans, when Telford made plans and proposed to do the work. The Government accepted, and Telford commenced to arrange for the work. He found it expedient to make an entire change of his plan, and finally, instead of a cast-iron, erected a suspension or chain bridge. At that day, his bridge was considered the greatest triumph of bridge building previously accomplished. It was really a great work; but at this day it would scarcely be more regarded for such a location, than the Quincy Railway as a pattern for railway making. Telford was a great man as an engineer, and is justly held in eminence, though subsequent experience has shown a better way. No doubt it will be so in future. Works great in one age of the profession, will be superseded by the greater experience of future times.

There are many important works in engineering that I have not time to notice, in a historic way, but I will ask your indulgence while I make some reference to railways.

We commenced with canals, and this, I think, was a favorable circum-

stance, inasmuch as it requires greater care in levels, and in guarding against the action of water. We have now been forty years on railways. It was said of a certain country, "That it was a finished country." Whatever may have been the propriety of that saying, it cannot be said our railways are finished railways. There is great range in the character of work that is called a railway. In this I have no reference to merely ornamental parts, but to those that relate to stability, permanence and utility. It has no unyielding necessity for a level grade. It may be laid very little above the flow of streams in time of floods. Its bed may be of common earth; that will do very well in dry weather, and when frost does not affect it. The grade in excavation may be too narrow to admit proper drainage. The cross ties may be of very perishable wood. The superstructure done in an inferior manner; and station buildings and shops of small extent, inconvenient in form, and of imperfect structure Now, do not suppose I am going to say all railways have been made in this defective style. But I may say, very few have been made that have not, more or less, the character I have given. Imperfect drainage, defective road-bed, and ill-arranged station grounds, buildings and shops, are to be seen on nearly all the railways in the country.

The want of transportation facilities in our widely extended and sparsely settled country, has, very naturally, been a material cause of our imperfect railway works. In addition to this, the want of experienced and competent engineers, to meet the great and sudden demand for such works, has, no doubt, contributed to the imperfection, and left much to be done before the railways will be in a condition to fully meet the usefulness they are capable of serving.

In railway building, for the most part, the engineer has been regarded merely as an expert, to run lines and levels, and compute quantities. When the work, in this respect, was done, he was regarded as of no more use, and to retain one of his assistants to do a little leveling or surveying, for some contingent work, was all that was regarded as necessary from his department. No doubt some engineers who have built railways, had no professional qualification to go further. No one can complain of them; they did all they supposed required of their profession, and this was, perhaps, all their employers expected of them as engineers. It may be said why not employ an engineer of more experience; to which it may be replied, they probably were not to be had. It has been a great error on the part of engineers and proprietors, that the impression to a great extent prevailed, that in regard to machinery, station grounds, buildings and shops, the

engineer gave way to the mechanic. This circumstance has put back the profession, keeping the engineer from the proper study of these duties, so that only a small comparative number have given proper attention to this important branch of professional duty. So long as the engineer did not assume these duties, the resort to the mechanic was very natural, and he would be regarded as best qualified to make up the complement of the railway. The excuse for this is, the profession in general had little knowledge of what was wanted in these respects, and the engineer was regarded as a sort of refined surveyor, and as knowing nothing about engines, cars and shops. Now, the professional point is, that the engineer's education should qualify him better than any other to provide for everything about a railway.

The engineer constructs a railway, and should know better than any other what sort of machinery is best adapted to its use. Of course, he will go to the mechanic for his engines, cars, &c., but he should know the general character, and be able to specify the leading or principal characteristics of what he wants. Certain accommodations will be wanted for the current use and repair of the machinery, which requires much thought and care, on the part of the engineer, to secure the greatest convenience and economy in the operations of business. In most cases, it will be necessary to keep in view the enlargement of stations and shops, to provide for a probable increase in traffic, and, while building for present wants, take care to provide, by method, for enlargement at a future day, with grounds secured for this purpose, so that no pulling down shall be required. In the history of our railways, it is palpable these things have been imperfectly considered. It has been stated why our works have been subject to these imperfections; but that does not excuse their want of improvement. One reason for neglect may be found, in the fact, that, for the most part, engineers did not regard this as properly belonging to their profession, and when a railway was put in operation they withdrew, as having accomplished their mission. As there was not much more to do in leveling, &c., the proprietary managers looked elsewhere to find men to conduct the operating business. We cannot blame the engineer for leaving, while new works were offered for his supervision, nor can the proprietors be blamed under the aspect of affairs then presented. The engineers, for the most part, did not regard the operating business as in their profession, and the managers supposed, as a matter of course, that other sources must supply their operating executive. In a few cases engineers were retained for this duty, but it has generally been otherwise. It is not to be supposed, that in the condition of the profession at the time alluded to, engineers would, in all cases, have acted wisely, or that they

would have been equally wise. They have varying capacity and skill, as in other professions, and the proprietary interest must judge of them as they do of others in selections for a professional duty. The main question is, will the engineer be more likely to conduct operating, with the necessary improvements of a railway, more judiciously than the man who has only a general knowledge of business? If such a question was applied to any other professional service, there could be no hesitation as to the answer. In the one case, it has been the special study to look into such matters. Hardly an engineer, who has constructed an important railway, that has not found the necessity of investigating the sources of traffic, as well as the building of the railway. This has demanded the consideration of the best means of conducting the traffic, in the most economical method. He knows he is making the work imperfect, and is naturally led to consider how this is to be remedied when the traffic shall furnish the financial ability. His previous training and reflection have given him, more or less, a correct view of the principles involved in successful management. On the other hand, the manager has had no scientific training, and very poor experience as to the duties he has engaged to perform. But men may learn, and after years of service they may come to appreciate the character of their duties; obtaining their education at a great expense to the institution.

For the most part, the latter class have had the operating management of our railways. Doubtless many of them have made considerable proficiency; but the railways are still imperfect, and few of them have yet learned that the great feature of operating management is to show in what way traffic can be conducted at the least expense; that is, in what way a ton of freight can be carried at the lowest rate. Certainly, to large extent, they seem to regard the largest engine and the longest train as the acme of skill, without regard to expense. Now, they talk a good deal about steel rails. Would it not be well to raise their rails above the floods, so that their trains need not be stopped for the flood to subside? Why is it, after thirty years of operation, the great New York Central is compelled to stop trains until the high water recedes? There is no necessity for this. A railway making a surplus dividend of eighty per cent. with their rails under flood line! To raise their track would improve their facility for drainage. I do not know that this would be very important, for they do not now properly improve the facilities they have for drainage. For an old and important railway to be churning out mud and water at the ends of their cross-sleepers, does not show perfection in the management. This is a serious matter; no railway can be good that is not well drained. Much ballast is lost by bad drainage. The

subgrade, or foundation, should be well formed, that water may drain off promptly, as, if it stands in pools under the ballast, it softens the foundation; ballast sinks into it, and the earth foundation of the bed will rise and eventually destroy the ballast. This circumstance, and the want of proper materials for ballast, has prevented, with few exceptions, our having a good road-bed. A large portion of the deterioration of rails has arisen from defective road-bed, and this, with the want of a proper joint, has been the main cause of deterioration of rails. These are evils that are tangible, and should be corrected, and then it will be time to consider the steel rail.

By an imperfect bed rails are rapidly destroyed, and the current expense of adjustment of rails is largely increased. The work of adjustment of rails is done little by little, and rarely any one keeps track of the expenses. If we but imperfectly maintain the road-bed for iron rails, is it probable we shall do better with steel rails? As it is the fashion of most railway men to put on the heaviest machinery the rails will bear, will they not increase this on steel rails? And what then becomes of the road-bed that does not support the iron rails? If properly used, the iron rails would do double the services they now do. It may be steel rails will be best, but first consider the road-bed. If that is not better cared for than at present, the steel rail will have a poor chance.

There is one point in which the laity railway men have greatly failed, and that is in their yards and shops. For the most part, railway shops have no evidence of systematic design. Convenience and economy seem to have been lost sight of, if ever seen. But I am getting tedious with details, and must stop this, or your patience will be exhausted.

Allow me to call your attention to the general aspect of this case. Is it not manifest that the railway, in itself and its appurtenances, would have been brought to a higher state of perfection if engineers had managed the execution in regard to improvements and operating service. On this point I have no doubt. A lay director will say, The engineer is quite necessary to build, but he knows nothing of the operating business. I have shown that his education is more specific in this respect, and better qualifies him than any other profession. It has been specially urged that in all mere business arrangements, the engineer is likely to be overreached by the shrewd business man. Now the fact is, the lay manager does not understand this business as well as the engineer. This is obvious from the consideration that skill, in all transactions in business, requires that a man know the cost of production. To this point the engineer's education directly tends, while all such knowledge by the lay manager must be had from several persons in

different departments, no one of which is able to analyze the whole. I regard this as sound theory, but I have had opportunity to notice practical results. In all the general business arrangements of railway companies, the most successful that I have known have been conducted by engineers. The lay manager often manifests much skill on a particular point, and seems, to himself and the outside observer, to have managed his case well. But the engineer has seen this point and all others that bear on the question, and thereby produces a result more beneficial to his institution. There are numerous ways in which the education of an engineer gives him superiority over the lay manager in all that concerns the maintaining, improvement and operating business of a railway. I give these views after mature consideration, and at a period of life that forbids any personal interest in the question. I am only influenced by a desire that railways may be perfected.

The only objection or reply that I may apprehend is, that engineers have sometimes failed in their management. No doubt this has been the case. A lawyer fails in some professional duty he had engaged to do; would that be a sufficient reason for taking a layman to conduct law business? Certainly not. A wise man would regard it as only a reason for greater discretion in selecting his legal adviser. The case should be the same in regard to an engineer. I advise, therefore, that engineers give more specific attention to the operating management of railways, and to study carefully their improvement, so far as previous work will permit beneficial improvements. The railway is a great machine, in which the track, shops, stations, yards, engines and cars are all to work in harmony, and should be conducted by an engineer, as the only person properly educated to comprehend all as one machine, and better fitted to make the whole work in an efficient and economical manner than any lay manager.

There are some difficulties that are, perhaps, peculiar to the engineer. He will sometimes have difficulty in satisfying his principals or the managing proprietors of the undertaking. There will be various methods suggested that he cannot consent to, and some he will regard as absolutely bad. He should expect this, and when the propositions come, look cautiously into the probable result, and set forth in as clear a light as he may be able, the reason for his objections. If the manager is a prudent man, a capable engineer will generally be able to satisfy him that the proposition is not likely to result favorably, or that there may be grave doubts. But if he fails to produce such impression, let him reduce the proposition to such form of experiment as will, with the least loss, afford a demonstration that will satisfy the manager. It will not often happen that a discreet engineer will be baffled in what he may regard the best interest of the work he is conducting; but

instances will sometimes occur in which the manager will insist on the measures he proposes, and the engineer may not be able to establish the propriety of his own views. If the matter is not materially important, it will generally be best for the engineer to waive his own judgment and proceed in the experiment with as much caution as may be practicable, guarding, as much as possible, against injurious influence on the main usefulness and character of the undertaking. If, however, it be material, and likely to mar the usefulness and character of the work, he will be justified in resigning his charge; but this is not always necessary or expedient. The representative of the proprietor has the right of control, and if the special measure he may propose does not interfere with the just right of other parties that may be interested, the engineer may set forth, in distinct terms, his objection to it, and leave the proprietary interest to abide the result, taking care to give it a fair and judicious trial. There are many doubtful, and even weak propositions, urged with much plausibility, by men who think they understand the matter fully, and are at times supported by engineers of some experience, and others who feel themselves qualified to judge quite as well as the most experienced engineer. The latter may not be able to demonstrate the inadequacy of the plan, though he may feel assured it will not succeed. If, however, there are circumstances that compel him to make the trial, he should do it on the smallest scale that will demonstrate its character. And this should be the method of proceeding, even if the engineer looks favorably on the proposition. It is always wise to thoroughly prove a thing that proposes to be useful, on as small a scale as will give a fair trial, especially most patents that are worth proving at all.

In conclusion, I may say, The engineer eminently depends on character. The interests of others, in various ways, are committed to him. On his capacity for his profession, and his integrity as a man, reliance must be placed. He will meet many difficulties of a physical, and not a few of a moral nature. He is in a progressive calling, and has occasion to be constantly learning. I suggest a ready observation of what he may see; a constant study and reflection on the varied duties of his profession, and a watchful guard against committing himself until he is fully prepared to set forth his views clearly and decidedly. To neglect the latter will be very likely to embarrass, and may defeat the object of his labors.

Now, gentlemen, I am in my seventy-fourth year, and if my fifty years' service in the profession has enabled me to make any suggestions that may be useful in pursuing your duties in a profession that is eminently connected with the progress of civilization, I shall be happy in this brief service, though I have only been able to touch a few of the questions involved.

XIII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## TUNNELS OF THE PACIFIC RAILROAD.

A Paper read before the Society Jan. 5, 1870, by JOHN R. GILLISS, Civil Engineer, Member of the Society.

During the past summer the track has been completed across this Continent, and so much sooner than was thought possible, that the difficulties overcome are apt to be underrated. Some account of a single item in the great work may therefore be interesting.

Between Omaha and Sacramento there are nineteen tunnels. Four of these are on the Union Pacific, and fifteen on the Central. The latter, having been completed before those on the Union Pacific were commenced, will be spoken of first.

*Central Pacific Tunnels.*—The tunnels of the Central Pacific are nearly all near the summit, where it crosses the western range of the Sierra Nevada. The line here lies on steep hill-sides, in some cases being, for long distances, on a face of bare granite, more or less broken by projecting ledges and boulders, but with an average slope often greater than 1 to 1. In such places embankments were almost impracticable; the hills were too steep to catch the slopes, and most of the rock from cuts was thrown far down hill by heavy seam blasts. On these accounts

the line for two miles east of Donner Pass was thrown further into the hill than on original location, thus adding to the depths of cuttings and increasing the number of tunnels, but saving retaining walls, and where tunnels were made enabling the work to be carried on in winter. Another important object was the saving of snow-covering where tunnels were made, and giving a good foundation for it where they were not. It is within these two miles that seven tunnels are crowded.

A detailed account of each tunnel would be tedious. Their characteristics have therefore been condensed into a table. See Appendix A.

*Commencement of Work.*—Tunnels 1 and 2 are both west of Cisco, a small track ninety-two miles from Sacramento, and within thirteen of the summit. They were both finished in 1866. During the fall of that year the track reached Cisco, and as fast as the gangs of Chinamen were released they were hurried to the summit to be distributed among the tunnels in its vicinity. The year before, some gangs had been sent to summit tunnel No. 6, and commenced the cuts at its extremities; winter set in before the headings were started, and the work had to be abandoned. To avoid a repetition of such delay, the approaches to all the tunnels were covered with men, and worked night and day in three shifts of eight hours each. Thus time was saved, and the tunnel organization started at once. As an illustration of the hurry, I may mention walking two miles over the hills after dark, and staking out the east end of No. 12 by the light of a bonfire; at nine o'clock the men were at work.

In November and the early part of December there were several snow-storms, just enough to stimulate without delaying the work. The rough rocky sides of Donner Peak soon became smooth, slopes of snow and ice covering the trail that led from tunnel 8 to 9; it remained impassable until spring, and communication had to be kept up by the wagon-road, five or six hundred feet below. This, the Dutch Flat and Donner Lake wagon road, was opened soon after it was decided to adopt this route. From the Pass the descent toward the lake was over very rough ground, requiring heavy side cuts and retaining walls with numerous zig-zags to gain distance.

From this road the scene was strangely beautiful at night. The tall firs, though drooping under their heavy burdens, pointed to the mountains that overhung them, where the fires that lit seven tunnels shone

like stars on their snowy sides. The only sound that came down to break the stillness of the winter night was the sharp ring of hammer on steel, or the heavy reports of the blasts.

*Winter of* 1866–7.—By the time winter had set in fairly the headings were all under ground. The work was then independent of weather, except as storms would block up tunnel entrances, or avalanches sweep over the shanties of the laborers. Before tracing the progress of the work underground, it will be well to see the character of weather outdoors.

A set of meteorological instruments was furnished by Colonel Williamson, of the United States Engineers, consisting of barometer wet, dry, maximum and minimum thermometers. These, with wind, clouds, etc., were recorded three times a day, and hourly during ten days in each month. From this record the table of storms given in Appendix C was made.

*Snow-storms.*—These storms, forty-four in number, varied in length from a short snow squall to a two-week gale, and in depth from a quarter of an inch to ten feet—none less than the former number being recorded, nor had we occasion to note any greater than the latter. This, the heaviest storm of the winter, began February 18th, at 2 P. M., and snowed steadily until 10 P. M. of the 22d, during which time six feet fell. The supply of raw material was then exhausted, but the barometer kept low and the wind heavy from the south-west for five days more, by which time a fresh supply of damp air came up from the Pacific, and then, as the machinery was still running full speed, this was ground up without delay. It snowed steadily until March 2d, making ten feet snow and thirteen days storm. It is true that no snow fell for five days, but it drifted so furiously during that time that the snow-tunnel at east end of tunnel No. 6 had to be lengthened fifty feet.

These storms were grand. They always began with a fall in the barometer and a strong wind from the south-west, hurrying up the tattered rain-clouds or storm-scud in heavy masses. The barometer, which averaged twenty-three inches, would drop sometimes as low as twenty-two and a half. The thermometer was rarely below twenty degrees at the beginning of a storm, and usually rose to thirty-two degrees before its close, so that the last snow would be damp and heavy,

sometimes ending in a rain. The storms ended, and clouds were scattered by cold winds blowing over the eastern range of the Sierra Nevada; these raised the barometer and dropped the temperature at once. The lowest temperature of the winter was from a wind of this sort, five and a half degrees above zero.

Our quarters were at the east end of Donner Pass, but still in the narrow part. About the second or third day of a storm the wind would be a gale, sometimes ten pounds per square foot; and would plough up the new fallen snow to heap it in huge drifts beyond the east end of the pass. About thirty feet from our windows was a large warehouse; this was often hidden completely by the furious torrent of almost solid snow that swept through the gorge. On the cliff above, the cedar trees are deeply cut, many branches of the thickness of a man's wrist being taken off entirely by the drifting snow-flakes.

No one can face these storms when they are in earnest. Three of our party came through the pass one evening, walking with the storm—two got in safely. After waiting a while, just as we were starting out to look up the third, he came in exhausted. In a short, straight path between two walls of rock, he had lost his way and thought his last hour had come.

*Road-breaking.*—Of course these storms make the road impassable even for sleighs. They are opened by gangs of men kept there for the purpose with heavy ox sleds. The snow when new fallen is very light, so that a man without snow-shoes would sink to his waist or shoulders. Into this the oxen would flounder, and when they lay down, worn out, be roused by the summary process of twisting their tails. I saw three in one team so fortunate as to have had theirs twisted clear off, none left to be bothered with. The men were as regardless of themselves as of their animals. They took life easily in fine weather, but were out nearly all the time when it stormed. Late at night they could be seen shovelling on a bad drift at the corner of the warehouse, where the wind heaped in the snow faster than they could dig it out, and then a denser mass of flying snow would hide them altogether.

*Snow-shoes.*—We started with Canadian snow-shoes, but soon abandoned them for the Norwegian, each a strip of light wood ten to twelve feet long, four inches wide, and an inch and a quarter thick in the centre;

they taper in thickness towards the end, are turned up in front, and grooved on the bottom.

There is a broad strap in the middle to put the foot under, and a balancing-pole to steady, push, and brake with. The latter will be seen all-important, as a speed of twenty-five to thirty miles an hour is often attained on a steep hill side. During several winters the mails were carried across the mountains by a Norwegian named Thompson, on these shoes. It is said he made sometimes forty or fifty miles a day on them.

*Snow-slides.*—Snow-slides or avalanches were frequent. The storm winds being always from the south-west, form drifts or snow-wreaths on the north-east crests of hills. When these become too heavy, which is generally towards the close of the storms, they break off, and in falling start the loose snow below. This slides on the old crust. I never knew of a slide from the ground.

Near the close of one storm, a log-house with board roof, containing three Scotchmen, brothers, and sub-contractors with their gang, some fifteen or sixteen men in all, was crushed and buried up at day-break. The storm ended at noon Towards evening, a man coming up the road missed the house and alarmed the camp, so that by six o'clock the men were dug out. The bulk of the slide had passed over and piled itself up beyond the house, so that it was only covered fifteen feet deep. Only three were killed; the bunks were close to the log walls and kept the rest from being crushed. The snow packed around the men so closely that only two could move about; they had almost dug their way out; over the heads of the rest little holes had been melted in the snow by their breath. Most of them were conscious, and, strange to say, the time had passed rapidly with them, although about fourteen hours under the snow.

This event startled us, for at the top of the cliff, in front of the camp, was a snow-wreath forty or fifty feet long, projecting twenty feet, and of about the same thickness. We were uncertain when it would come down and where it would stop. A keg of powder was put down behind it next morning and fired. A white column shot up a hundred feet, and then the whole hill-side below was in motion; it came down a frozen cascade, covered with glittering snow-dust for spray. It was a rare sight, for snow-slides are so rapid and noiseless that comparatively few are seen.

They were so frequent across the trail leading to tunnel No. 9, that it had to be abandoned for some months. At tunnel 10, some fifteen or twenty Chinamen were killed by a slide about this time. The year before, two road repairers had been killed, and buried too, by a slide, as their bodies were not found until spring.

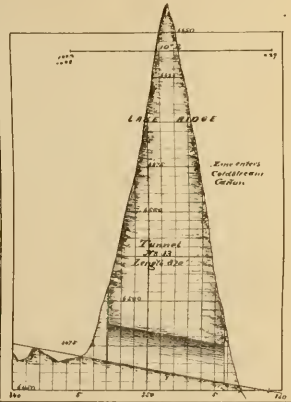
The name given to pass, peak, and lake, is itself the record of a tragedy. In the fall of 1846, the Donner party of emigrants from the East delayed crossing until too late. Nearly all died of starvation; the few survivors had prolonged their lives by cannibalism.

*Snow-tunnels.*—Before the snow had acquired depth enough to interfere much with the work, the headings were all started. The cuts at their entrances soon filled up with snow, but drifts were run through them, in some instances large enough for a two-horse team. Through these snow-tunnels, whose lengths varied from 50 to 200 feet, the material excavated was hauled in carts or on sleds to the waste banks. These snow-tunnels kept settling at the crown, so that they had to be enlarged from time to time, otherwise they were perfectly satisfactory.

The most remarkable snow-tunnel was made to connect the two ends of tunnel 8. The spur through which this is made terminates in a vertical bluff of granite a hundred feet high. To get around it during the fall, a rope was fastened to the rocks at a point where there was a steep descent of thirty or forty feet. During the early part of winter a snow-drift formed on the face of this bluff, descending in a steep slope from its top to the wagon road, two hundred feet below. On this slope a trail was cut and used for a month or two.

Later in the winter, when the accumulation of snow made it practicable, a snow-tunnel was excavated through the drift, and around the face of the bluff. Windows were made at short intervals for light, and to throw the material out in excavating, and steps cut where a descent was necessary. One flight of these led down to the blacksmith's shop, buried still deeper in the snow, while the main passage led into one already excavated at the east end of tunnel 8. The snow kept settling down hill and away from the bluff, so that there was an open space of three or four feet between it and the rock towards the close, which was far from inspiring much confidence in the route.

Between tunnels 7 and 8 there is a deep ravine, in crossing which the




# PROFILES

OF TUNNELS 6 TO 13

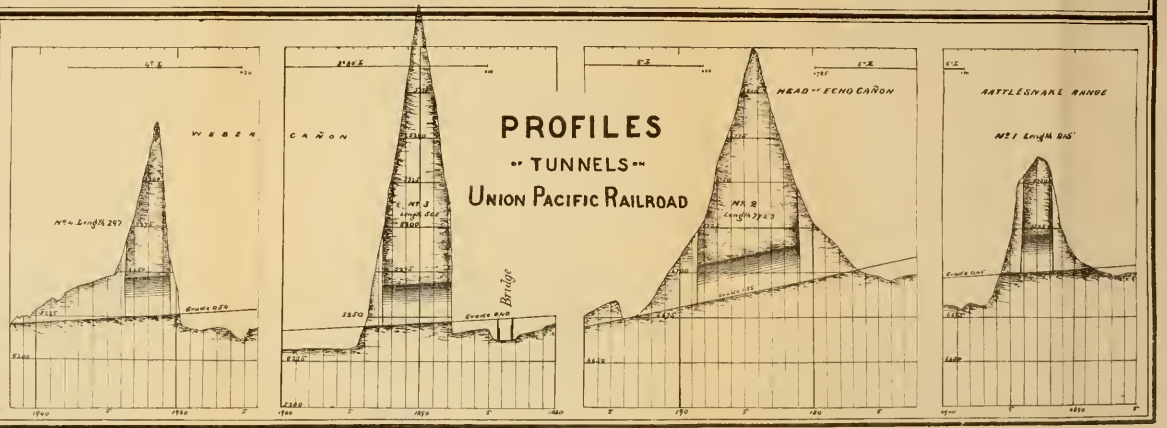
## CENTRAL PACIFIC RAILROAD

From Summit of Sierra Nevada

Eastward

Vertical lines 100' apart.

Horizontal „ 5' „ .




# PROFILES

OF TUNNELS ON

## UNION PACIFIC RAILROAD

Photohth by the N.Y. Lithog. Eng & Printg Co. 16 & 18 Park Place

road has a 4x5-feet box culvert, and a retaining wall on the lower side of 75 feet extreme height. The foundation was begun in fall, but stopped by winter, and the ravine filled with snow. Next spring a snow-tunnel was commenced about two hundred feet down the ravine, and run in to strike the unfinished foundation. Smaller tunnels were run to quarry stone got out in fall, and a cave dug over the foundation large enough to work in. The culvert was built, and by the time it was finished the depth of snow overhead had decreased to twenty-five or thirty feet; this was excavated by a stream of water, and the retaining wall commenced.

*Snow-cuts.*—In spring, when the road has begun to be bare, so that sleighs can no longer be used, there are very heavy banks of snow to cut through to make the road passable for wagons.

In June I measured one of these cuts through the end of a snow-slide, and found it twenty-five feet deep. A week later the road was dusty in the centre, but the snow banks were not all gone until July, so that we had at that place the strange spectacle of sprinkling-wagons watering a road between two walls of solid snow.

*Alignment.*—As soon as each heading became sufficiently advanced, the centre line was secured, generally by small holes drilled in the roof, with wooden plugs and tacks. These points were placed as far apart as length excavated would permit, and from them the line produced as the work advanced. In most cases the entrances were afterwards so blocked up with snow that it was impossible to recur to the line outside, and the tunnels were completed from the points first put in.

In running lines outside during the winter, it was generally necessary to make deep cuts, and sometimes tunnels, through the snow, to get at the original transit points.

Most of the tunnels are on curves, No. 13 being on one of 573 feet radius, with 87 degrees of curvature inside the tunnel. In this, as in No. 11, the usual difficulties of working with instruments by candle-light were much increased by the numerous temporary timbers in the headings. The lines met in the centre of the tunnel, parallel to each other, but two inches apart. In the other cases the discrepancies were too slight to notice.

*Dimensions.*—Most of the work was through solid rock, which did not require lining, and the following dimensions were adopted: Bottom, a rectangle, 16x11 feet; arch, a semi-circle, 16 feet in diameter; grade at centre of tie, and one foot three inches above sub-grade.

Tunnel 11 was partly, and tunnel 13 wholly, lined with timber in the following manner: 12"x12" sills were placed on each side, and posts 12"x16" morticed into them. The latter support arches, each composed of three thicknesses of 5"x12" plank, breaking joints, and bolted with ¾-inch iron bolts, thus making a solid arch of 180 square inches sectional area. The distance from centre to centre of arches varies from one and a half feet to five feet, according to material. Over the arches, and, where the material required it, on the sides also, split lagging about two and a half inches thick was put in. The width at sub-grade inside of posts is seventeen feet; at springing line inside of arches, nineteen feet; giving a batter of one foot on each side. Height of crown above grade, nineteen feet nine inches, thus leaving room for masonry inside the temporary wooden lining.

Tunnels 1 and 2 were lined in a similar manner, except that the batter of side posts was only six inches.

In these tunnels, through soft material, the heading was supported by temporary timbers. Chambers were then excavated at the sides to below sub-grade, for the sills, and the central core left to support the shores which held the material above in place. As the timbering advanced, the core and false work were removed.

In tunnel No. 12, a short distance in the centre was found to be decomposed granite, and after the tunnel was excavated a light set of timbers was put in. They consisted of arches, each composed of seven pieces of 10x10-inch timber, with side-posts and sills similar to those already described.

In all the tunnels on curves, allowance was made for elevation of outer rail, so that top of cars would remain in centre of opening.

*Laborers.*—With the exception of a few white men at the west end of tunnel No. 6, the laboring force was entirely composed of Chinamen, with white foremen—the laborers working usually in three shifts of eight hours each, and the foremen in two shifts of twelve hours each. A single foreman, with a gang of thirty to forty men, generally constituted

the force at work at each end of a tunnel; of these, twelve to fifteen worked on the heading, and the rest on bottom, removing material, etc.

When a gang was small, or the men needed elsewhere, the bottoms were worked with fewer men, or stopped so as to keep the headings going.

The Chinamen were as steady, hard-working a set of men as could be found. They were paid from $30 to $35, in gold, a month, finding themselves, while the white men were paid about the same, but with their board thrown in. The force at work on the road probably averaged from six to ten thousand, nine-tenths of them being Chinamen.

*Progress.*—Records were kept of weekly progress, and number of working days in tunnels 3 to 13 inclusive, from which the accompanying table, Appendix A, is principally taken. The headings were worked steadily until they were through; the force was then crowded on the bottoms, which had, by that time, fallen behindhand. The progress made on them, under these circumstances, is shown in the last column.

*Cost, etc.*—An approximate estimate of cost of excavation of tunnel No. 6 is given in Appendix D, showing it to have been about $14.80, gold, per cubic yard with powder, and $10 with nitro-glycerine.

*Tunnel No. 6.*—This, the longest tunnel of the road, is parallel to and about four hundred feet north of Donner Pass. Its length is 1,659 feet, and greatest depth below the surface, 124 feet, measuring from grade. The material is granite, of a medium quality, crossed by seams in every direction.

To expedite the work a shaft was sunk about the middle of the tunnel, its dimensions being 8x12x72.9 feet.

Work was commenced on the shaft August 27th, and for the first thirty feet it was sunk at the rate of a foot a day, after which its progress slackened, from delay in hoisting the material with a common hand derrick.

Meanwhile a house was being built over the shaft, and the hoisting engine was put up. The latter consisted of an old locomotive, the Sacramento, and, by an interesting coincidence, the first engine run in the State. This was geared to a drum six feet in diameter. The house was fifty feet square, containing, in addition to the hoisting apparatus, forges, fuel, tamp-

ing, etc., so that when snowed in, these articles would be close at hand. The shaft was divided by planking into two compartments, each five feet square; over these were two "jiggers" or transfer tables. The buckets were first of wood, then two additional ones were made of boiler plate, four feet nine inches square by two feet six inches high, outside dimensions, and fitted for side dumping. They were loaded at the face of the work below, run on trucks to the bottom of the shaft, hoisted and transferred to other trucks to run out on the waste bank.

Total days' work on shaft, 85; average progress, 0.85 feet in twenty-four hours. Nitro-glycerine had not yet been introduced; with it the progress would probably have averaged 1.5 feet.

*Nitro-Glycerine.*—This was introduced on the work early in 1867, to expedite progress of the summit tunnel. It was made on the spot by Mr. James Howden, and used in the four headings of tunnel No. 6 from Feb. 9th, and to some extent in tunnel No. 8, but not enough to give data for comparison. After the headings of these tunnels were through, it was used in the bottoms.

In the headings of summit tunnel the average daily progress with powder was 1.18 feet per day, with nitro-glycerine, 1.82 feet, or over 54 per cent. additional progress.

In bottom of summit tunnel, average daily progress with powder, full gangs, was 2.51 feet; with nitro-glycerine, 4.38, or over 74 per cent. in favor of nitro-glycerine. The same number of men were used with both explosives.

The additional progress in heading was due, principally, to the use of one and a quarter inch drills instead of two and a half inch, as required by powder.

In the bottoms the difference was principally due to fewer holes being required, and to the granite being broken into small pieces that seldom needed new holes to split them on. In both headings and bottoms less time was found to be required to clear the tunnels of smoke with nitro-glycerine than powder.

The cost of nitro-glycerine made at Donner Pass, according to Mr. Howden, was about 75 cents per lb.

It was considered there to be about eight times as powerful as the

same weight of powder, which would make it the cheapest, viewed simply as to expense of producing a given effect.

Wherever practicable, I have no doubt that it is safest to manufacture nitro-glycerine on the site where it is to be used, and from day to day as required. At Donner Pass I only recollect two accidents, and those would have happened with powder.

The conclusion we may safely come to, from the Central Pacific work, is, that in hard rock tunnels, with the same number of men, over fifty per cent. additional progress can be made by using nitro-glycerine in place of powder, and the expense will be reduced proportionately.

Since papers have been read before this Society on the subject by Messrs. North and Chester, it is unnecessary to speak of the details of manufacture and use of this agent.

*Tunnels of the Union Pacific Railroad.*—A detailed list of these tunnels will be found in Appendix F.

Tunnel No. 1 is on St. Mary's Creek, about 680 miles west from Omaha, and 12 miles east of second crossing of North Platte River. It was commenced April 30th, 1868, and continued from each end until June 8th. At that time the two headings were in 86 and 87 feet respectively, the progress having averaged 2.22 feet per day. A soft spot was then found in the west end, and there being no means of lining without delay, the open cut was extended to cover the place, and the length of tunnel reduced to 215 feet.

This delayed the work, so that a temporary track had to be built around it.

Tunnel No. 2 is at the head of Echo Cañon, in Utah, about 972 miles from Omaha. Its length is 772.3 feet, being the longest of the Union Pacific. The approaches were started in July, 1868; they are heavy cuts through clay. Rock was struck about the end of August, and found to be like the prevailing formation in the vicinity, an indurated clay, with occasional streaks of soft sandstone. Most of it drilled very easily, but required as much powder in blasting as ordinary rock. While damp it stood firm, but after sufficient exposure to the air to dry out the moisture, it cracked and crumbled like lime in slacking. These qualities made the work very expensive; rock prices had to be paid, and earth slopes taken out.

In starting the headings they had to be supported the same day the excavation was made; but on getting fairly in, the roof would stand well a week or two.

There was an irregular streak of blue sandstone which ran completely through the tunnel near the springing line.

The headings were started at the west end August 29th, and at the east end September 5th; they met January 30th, 1869. The tunnel was finished April 3d, 1869.

When work was commenced on the tunnel the track was still three hundred miles east, and all the available transportation required to haul tools, materials, and provisions over this gap; it was useless even to think of getting cement in time. There was no suitable stone near the work, and the clay had too much lime to make brick. On these accounts the tunnel had to be lined with timber.

While waiting for the latter to be sawed, the headings were secured temporarily by bents framed as shown on Plate 2.

The permanent timbers consist of arches placed four feet apart, centre to centre, and similar to those already described on the Central Pacific Railroad. (See Plate 2.)

They differed from those of the Central Pacific in having a longitudinal stringer on each side at the springing line. This guards against the effects of unequal lateral pressure, and enabled the excavation to be taken out more economically. Instead of chambering to sub-grade and building up from the bottom sill, the chambers were cut only to the springing line, the stringers laid, and the arches raised and lagged. The bottom was then taken up, leaving a bench to support stringers. When the bottom was all out, the stringers were under-pinned, the benches cut away, and the lower timbers put in.

The roof was lagged throughout; the sides, for about two hundred feet at each end, and the remainder left to be finished after the track was laid. For lagging, round and split poles were first used, but afterwards two and a half inch plank.

The excavation of the tunnel was let by contract to Miller & Patterson; their expenses in timbering were paid as extra work. The detailed cost is given in Appendix F. The excavation required two pounds powder and two and seven-tenths feet fuze per cubic yard. The heavy work on each side of the tunnel was not ready for the track, and a tem-

porary line of eight miles in length was built around it This line started about a mile west of Wahsatch—descended into the cañon by two Ys, and followed the main ravine to near Castle Rock station, where it regained the main line. The latter was finished May 25, 1869.

Tunnels Nos. 3 and 4. These are in the Weber Cañon, Utah, three-quarters of a mile apart, and about one thousand and five miles west from Omaha.

They were started under the direction of Thomas H. Bates, Division Engineer. When about one-third done, he was relieved by E. P. North, to whom I am indebted for the details of their construction. In January, 1869, it was feared these tunnels would not be through in time for the track, and Mr. North was directed to run temporary lines around them. Instead of that, he suggested hastening the work by using nitro-glycerine; which was done with very satisfactory results, as will be seen.

*Tunnel No.* 3.—This tunnel is through a sharp spur of black limestone and dark blue quartzite, two hundred and sixty-six feet of the former and two hundred and forty-two feet of the latter, total length five hundred and eight feet, on a 3 deg. 30 min. curve to the left. The headings were commenced about September 1, 1868, and met April 4, 1869. Until December 27th the work was part of Brigham Young's contract, and sub-let to Sharp and Young. It was then carried on as company work, and let to Daniel McGee, a "Gentile," February 9th. Not being finished in time for the rails, a temporary track was built around it, partly on a 22 deg. curve, two hundred and sixty feet radius, around which trains of twenty-three cars were taken.

Nitro-glycerine was fairly introduced into the tunnel by February 23d. About twenty per cent. of the tunnel men struck on account of its use, and were not replaced as two shifts on the bottoms were found enough to keep them up with the headings, notwithstanding the additional progress they too were making; three shifts had been required with powder. The progress of this tunnel, under various circumstances, is given in Appendix E. It will be seen that, after allowing for the smaller force employed, about twice as much work was done per man, with nitro-glycerine as with powder. The use of nitro-glycerine in tunnel No. 3 saved the Company nearly $40,000.

*Tunnel No.* 4.—Length two hundred and ninety-seven feet; alignment

4 deg. to left; material, quartzite, similar to that in tunnel No. 3. Headings were commenced about September 10, 1868, and tunnel finished January 29th; nitro-glycerine was used to take up the last one hundred and eighty feet of bottom, which it did in eleven days; making the remarkable progress of 8.18 feet per day from each end. In tunnel No. 4, one thousand nine hundred and sixty cubic yards were taken out with powder, requiring two hundred and eighty-nine kegs and seven thousand feet of fuze, or three seven-tenths pounds powder and three six-tenths feet fuze per cubic yard.

*Comparison between the two roads.*—The total length of tunnelling on the Central Pacific is six thousand two hundred and thirteen feet, on the Union one thousand seven hundred and ninety two. The cross sections of tunnels on the two roads are practically identical.

The circumstances and materials varied too much to make an accurate comparison of progress in tunnels of the two roads. The greatest average daily progress of heading on the Central Pacific, through granite with nitro-glycerine, was 3.29 feet. On the Union Pacific, through quartzite about as hard as granite, 4 62 feet. Each road has done over eight feet per day at a single face in taking up bottom.

The laborers on the Central Pacific were mostly Chinamen, paid $30 to $35 gold per month, working three shifts per day in tunnels, and twelve to fifteen men in a heading. On the Union Pacific the laborers were white men, paid $3 to $4 per day currency, generally working two shifts per day, and eight to twelve men in a heading on tunnels 1 and 2, and three shifts of fourteen to sixteen on tunnels 3 and 4.

The Central Pacific Railroad was built under the direction of S. S. Montague, Chief Engineer. The location and construction across the Sierra Nevada were in charge of L. M. Clements, Resident Engineer. The account of tunnels on that work is principally compiled from a report on the subject written for the latter by the author, while engaged on tunnels 6 to 13 of that work.

The Union Pacific Railroad was built, and its location revised, under the direction of S. B. Reed, Engineeer and Superintendent of Construction. The accounts of tunnels 1 and 2 are from personal observation, and of tunnels 3 and 4 from data furnished by Edward P. North, Resident Engineer of work in Weber Cañon.

# Appendix A.

*Tunnels of Central Pacific Railroad.*

S. S. Montague, *Chief Engineer.* I. M. Clements, *Resident Engineer.*

| Number. | Distance in miles from Sacramento. | Locality. | Alignment. | Material. | Length. | | | Greatest depth. | No. of faces worked. | Heading. | | Bottom. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Not lined. | Lined. | Total. | | | Total work'g days 24 hours. | Average daily progress. | Total working days. | Average daily progress. | Daily progress, full gauge. |
| 1 | 77 | Grizzly Hill | .. | Conglomerate | 226 | 232 | 498 | .. | .. | .. | .. | .. | .. | .. |
| 2 | 84 | Emigrant Gap | .. | " | .. | 271 | 271 | .. | .. | .. | .. | .. | .. | .. |
| 3 | 92 | Cisco | 9° R | Hard trap | 280 | .. | 280 | .. | 2 | 354 | 0.79 | 280 | 0.89 | 1.43 |
| 4 | 93 | Red Spur | 8° R | " " | 92 | .. | 92 | .. | 1 | 128 | 0.72 | 101 | 0.91 | 1.63 |
| 5 | 97 | Crocker's Spur | 8° R | Granite | 128 | .. | 128 | . | 1 | 213 | 0.60 | 144 | 0.89 | 1.48 |
| 6 | 105 | Summit | T | " | 1659 | .. | 1659 | 124 | 4 | 396 | 1.18 | 621 | 1.42 | 2.51 |
| " | " | " | " | " | .. | .. | .. | .. | .. | *a*655 | *a*1.82 | *a*178 | *a*4.38 | *a*4.38 |
| 7 | 105 | " | T | " | 100 | .. | 100 | 41 | 1 | 113½ | 0.88 | 63½ | 1.57 | 2.00 |
| 8 | 106 | Black Point | T | " | 375 | .. | 375 | 169 | 2 | 399½ | 0.94 | 260½ | 1.44 | *a*3.82 |
| 9 | 106 | Donner Peak | T | " | 216 | .. | 216 | 46 | 1 | 171½ | 1.26 | 152 | 1.42 | 2.29 |
| 10 | 107 | Cement Ridge | 8° L & T | Conglomerate | 509 | .. | 509 | 67 | 2 | 202½ | 2.51 | 143 | 3.56 | 4.91 |
| 11 | 107 | Tunnel Spur | T & 8° R | Granite, partly | 325 | 252 | 577 | 74 | 2 | 356 | 1.62 | 494½ | 1.17 | *b*2.19 |
| 12 | 107 | " " | 8° R | Decomposed | 262 | 80 | 342 | 78 | 2 | 268 | 1.28 | 184 | 1.97 | 1.97 |
| 13 | 112 | Lake Ridge | 10° R | Conglomerate | .. | 870 | 870 | 210 | 2 | 389 | 2.24 | 335 | 2.59 | 3.15 |
| 14 | 134 | Alder Creek | .. | Trachyte | 200 | .. | 200 | .. | .. | .. | .. | .. | .. | .. |
| 15 | 137 | Quartz Spur | .. | Soft granite | 96 | .. | 96 | .. | .. | .. | .. | .. | .. | .. |
| | | Total | | | 4508 | 1705 | 6213 | | | | | | | |

*a.* Using nitro-glycerine; all others with powder. *b.* In east end—hard granite.

## Appendix B.

*Abstract of preceding Table—Average Daily Progress in different Materials. The bottom progress is for full gangs.*

| Material. | Explosive. | From Tunnels | Heading. | Bottom. |
|---|---|---|---|---|
| Hard Trap..... | Powder..... | 3 and 4..... | 0.76 | 1.53 |
| Hard Granite ..... .... | " ..... | 5, 6, 7, 8, 9 .. | 0.97 | 2.09 |
| " " ..... | Nitro-Glycerine | 6..... | 1.82 | 4.38 |
| Conglomerate..... .. | Powder..... | 10 and 13.... | 2.38 | 4.03 |
| Hard Granite ..... | " ..... | Shaft in No. 6 | 0.85 | .. |

## Appendix C.

*Snow Storms at Donner Pass, California, Winter of* 1866–67, *during which most of the preceding work was done.*

| Month. | Number of Storms. | | Depth of Snow. | | |
|---|---|---|---|---|---|
| | 1′ and 1 over | Under 1′. | Fallen during Month. | Average Depth. | Maximum Depth. |
| | | | ′ ″ | ′ ″ | ′ ″ |
| November, '66..... | 3 | .. | 4 6 | 1 0 | 1 6 Nov. 4. |
| December, '66..... | 4 | 5 | 10 10½ | 5 0 | 9 0 Dec. 20. |
| January, '67..... | 3 | 7 | 11 00½ | 8 0 | 10 6 Jan. 24. |
| February, '67..... | 3 | 5 | 10 3½ | 10 0 | 12 8 Feb. 22. |
| March, '67..... | 2 | 9 | 4 2¼ | 12 6 | 14 4 Mar. 2. |
| April, '67..... | 1 | 1 | 3 6 | 13 0 | 15 1 Apr. 13. |
| May, '67..... | .... | 1 | 3 | 8 6 | 11 0 May 1. |
| June, '67..... | .... | .. | .... | 3 0 | 6 0 June 1. |
| Sums and means ... | 16 | 28 | 44 7¾ | 7 0½ | |

## Appendix D.

*Estimated Cost of Excavation in Tunnel No. 6, Central Pacific Railroad (Granite with Powder); average progress, 35′ per month.*

Cost of each heading and bottom per month:

| | | | | |
|---|---|---|---|---|
| 100 | men per day (in 3 shifts) | at | $31 00 | $3,100 00 |
| 2 | foremen; pay, $90; board, $30 | " | 120 00 | 240 00 |
| 3 | horses | " | 50 00 | 150 00 |
| 3 | blacksmiths; pay, $85; board, $30 | " | 115 00 | 345 00 |
| 3 | helpers; pay, $50; board, $30 | " | 80 00 | 240 00 |
| 40 | kegs powder | " | 4 00 | 160 00 |
| 150 | lbs. candles | " | 40 | 60 00 |
| 400 | bushels charcoal | " | 20 | 80 00 |
| 1,500′ | fuze | " | 3 00 | 45 00 |
| | Superintendence, tools, etc | 20 per cent. | | 884 00 |
| | | | | $5,304 00 |

Or $14.80, gold, per cubic yard. With nitro-glycerine the cost must have been about $10 per cubic yard.

## Appendix E.

*Tunnels of Union Pacific Railroad.—S. B. Reed, Eng. and Supt. Construction.*

| No. of Tunnel. | REMARKS. | Distance from Omaha in Miles. | Length. | Alignment. | Depth. | No. Faces worked. | Average Daily Progress. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Heading. | Bottom. |
| 1 | Soft sandstone..... | 680 | 215 | Straight, | 64 | 2 | 4. | 6. |
| 2 | Clay rock..... | 972 | 772 | " | 135 | 2 | 4. | 9. |
| 3 | Limestone and quartzite.. | 1,005 | 508 | 3° 30′ L | 178 | 2 | | |
| " | Mormons with powder.... | .. | .. | .... | | .. | 1.03 | 0.57 |
| " | Gentiles " .... | .. | .. | .... | | .. | 2.70 | 3.17 |
| " | " with nit. gly..... | .. | .. | .... | | .. | 4.62 | 4.62 |
| 4 | Quartzite..... | 1,006 | 297 | 4° L | 108 | 2 | | |
| " | Mormons with powder.... | .. | .. | .... | | .. | 1.38 | 0.92 |
| " | " " nit. gly.... | .. | .. | .... | | .. | ... | 8.18 |
| | | | 1,792′ | | | | | |

Note.—Progress in tunnels 1 and 2 is when working full gangs.

## Appendix F.

*Estimated Cost of Tunnel No. 2, Union Pacific Railroad.*

| | | | |
|---|---|---|---|
| Excavation of tunnel—12,410$\frac{1}{2}$$\frac{1}{0}$ cubic yards, at $11.50 | | | $142,715 57 |
| Carpenter work | $11,434 20 | | |
| Blacksmith | 1,711 50 | | |
| Teams hauling timber at tunnel | 2,053 50 | | |
| Laborers on timbering | 17,334 50 | | |
| Lights " | 340 10 | | |
| Miscellaneous | 206 55 | | |
| Cost of putting in timber | $33,080 35 | | 33,080 35 |
| Loading and hauling timber | $18,543 00 | | |
| Timber used in tunnel—304,114 ft. Bm., at $30 | 18,246 84 | | |
| Iron in bolts—8,032 lbs., at 20c. | 1,606 40 | | |
| Cost of materials | $38,396 24 | | 38,396 24 |
| Total cost of tunnel | | | $214,192 16 |
| Cost of excavation to contractors: | | | |
| Foremen 1,188 days at $7 00 | $8,316 00 | | |
| Mechanics 2,640 " " 5 00 | 13,200 00 | | |
| Teams 1,604 " " 10 00 | 16,040 00 | | |
| Laborers 16,846 " " 3 50 | 58,961 00 | | |
| Powder 1,064 kegs " 10 00 | 10,640 00 | | |
| Fuze 33,200 ft. " 3¼ | 1,079 00 | | |
| Candles 3,450 lbs. " 45 | 1,552 50 | | |
| Lamp oil 310 gals. " 3 50 | 1,085 00 | | |
| Steel 1,798 lbs. " 30 | 539 40 | | |
| Superintendence, tools, coal, buildings, etc., at 20 per cent | 22,282 58 | | |
| | | $133,695 48 | |
| Deduct timbering expenses paid by Company | | 31,026 85 | |
| | | $102,668 63 | |
| Cost of work on timbering per lineal foot | | | 42 83 |
| " materials for " " " | | | 49 72 |

XIV.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

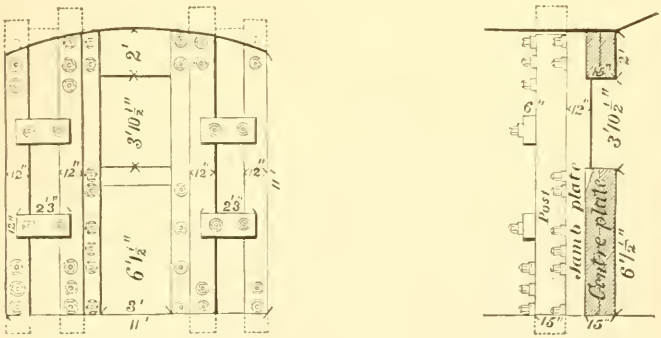
INCORPORATED 1862

# TRANSACTIONS.

## EXPERIMENTS ON THE FRONT OR SHIELD OF THE EXPERIMENTAL CASEMATE AT FORT MONROE.

A Paper read before the Society Feb. 2, 1870, by Bvt. Major-General J. G. Barnard, U. S. Corps of Engineers, Member of the Society.

The iron front or "shield" of the "experimental casemate" at Fort Monroe, which formed one of the targets for the firings in October, 1868, is described as follows:




The shield was composed of two 12-inch plates 4 feet broad, one on each side of the embrasure, each plate being supported on the back by two vertical iron posts, 12″ × 15,″ which were bolted to the plates and stepped above and below into the granite masonry.

A pair of clamps (2 3″×1′×6″) secured with double bolts to the plate in front, aided to hold the plates and posts in juxtaposition. Below the

embrasure opening, and lapping 8 inches on either plate, was a centre or sill piece 4 ft. 8 in. broad and 6 ft. 1½ in. high, and 15 in. thick, made of two 7½ in. plates, which were bolted at the lapping, to the jamb pieces; and above the embrasure opening, was a narrow iron lintel, also made of two 7½ in. plates, and lapping on and bolted to the jamb plates like the sill piece. The whole shield presented a front 11 feet broad and 12 feet high.

The adequacy of the forged beams, or "posts," as the supports of the shield, was doubted prior to the actual trial; especially as the powder charges of the guns to be used (the 15 in. smooth bore and 12 in. rifle) had been increased, subsequent to the designing of the shield, from 55 lbs. for each, to 100 lbs. for the former, and 70 lbs. for the latter.

Although it is a subject in which attempts at exact calculation must be illusory, yet there are principles by which a rude estimate of the strains to which such supports will be subjected may be formed; while, on the other hand, the "work" the posts and superimposed plates will do in bending up to fracture, may be calculated; *provided, always*, that we assume that iron, thus instantaneously strained to fracture, will exhibit an equal extension of fibre as when fractured by slowly applied strains, and moreover that the co-efficient of elasticity remains constant. These assumptions we know, however, are not sustained by facts. But, independently of such calculations, we know that when a massive body—an iron turret, for example, or a casemate shield—is struck by a projectile, but a very trifling amount of the "work" in the latter is available to break the supports. It is to this fact that the spindles and gearing of turrets owe their security. The fact is readily accounted for, but the precise degree of immunity, or, in other words, the proportion of the "vis viva" of the projectile *available* to their breaking, can only be calculated by making assumptions more or less arbitrary.

In the case of the shield in question it might be estimated that not more than $\frac{1}{25}$ of the work of the projectile would be available to break the beams,* and that the "work" of bending to fracture the beam and

*

Let $A\ O\ A'$ be a plate or beam held at its extremities $A$ and $A'$ and struck by a projectile at its middle point $O$.

superimposed plate would amount to something like 500,000 ft.-lbs., *on the above assumptions.*

The actual performance of the beams may be briefly stated as follows:

The first shot from the 15-in. gun struck one of the jamb plates opposite about the middle of the beam next on the right of the embrasure (the right *as seen in* accompanying sketch). Anticipating the fracture, the gun was fired (at 150 yards) with a 450 lb. cast-iron projectile and a reduced powder charge of 37 lbs. The shot struck with a calculated velocity of 884 feet and an energy of 5,500,000 ft.-lbs. An "indentation" in the plate, 14 inches in diameter and 2¼ inches deep, was made, the plate was slightly cracked and the beam completely ruptured. In this case the *available* energy of the shot (calculated per formula (1) of appended note) was but about 183,000 ft. lbs.

The second shot was from the rifled gun, with a 683-lb. steel projectile, and 70 lbs. of powder. It was aimed at the middle of the "centre-plate," but hit towards the upper corner. It tore off a piece of the outer thickness of that plate, but did little other damage.

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Let $P$ = weight of projectile.

$V$ = its striking velocity.

$l$ = length $A\,A'$ of plate.

$D$ = weight of unit of length of plate.

$v$ = the common velocity of the point $O$ of the plate and of the projectile *after impact.*

The plate in bending would form a curve $A\,O\,A'$; but it is accurate enough for present purposes to consider the lines, $A\,O$, $A'O$, to be straight, in which case the *mean* velocity of all points of the plate would be $\frac{1}{2}\,v$, and the equation of momentums, before and after impact, will give

$$P\,V = \tfrac{1}{2}\,v\,(D\,l + 2\,P)$$

which gives, if $D\,l$ is so large that $2\,P$ may be neglected,

$$v = 2\,\frac{P\,V}{D\,l}$$

Any point, $a$, moves with the velocity $\frac{x}{\frac{1}{2}\,l}\,v$, or, substituting value of $v$, $\frac{4\,P\,V}{D\,l^2}\,x$;

and the "work" in the length $d\,x$ of plate is $\frac{D\,d\,x}{2\,g}\left(\frac{4\,P\,V}{D\,l^2}\,x\right)^2$

Integrating from $x = o$ to $x = \frac{1}{2}\,l$ and doubling the result, we get for the work imparted to the plate and available in breaking it

(1) $$\frac{4\,P}{3\,D\,l} \times \frac{P\,V^2}{2\,g}$$

The second factor is the striking energy (or "work") of the projectile. The first is the fractional part available as above. All the rest of the work of the projectile is consumed in *making the indentation*, and in effects generally

The third shot was aimed at, and hit, the middle of the "centre-plate." It was a steel sphere, weighing 480 lbs., thrown by 100 lbs. of powder. It struck with a calculated velocity of 1,392 feet, and an energy of 14½ millions of foot-lbs. Its effects were almost totally expended upon the centre-plate, the indentation in which was 6 inches deep—the upper part of the face-plate was rent off, and the back plate was bulged 5⅜ inches, with radial lines of cracks nearly at right angles to each other. The shot did not break up. The space moved through from first impact to stoppage was made up of the depth of indentation (6 inches), and whatever yielding took place in the plate and shield. It could not have exceeded one foot. Hence a *mean* static pressure of 14½ millions of lbs., *at least*, must have been developed. No other posts were broken by the shot, nor was the fractured one sensibly disturbed.

The fourth shot, a chilled iron parabolic headed projectile, weighing 658 lbs., thrown from the same gun, with a maximum powder charge of

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small in comparison, such as vibrations, splitting of plates, breaking of bolts, etc. To make application to the shield we will consider one post or beam and one half (in width) of the superimposed plate as being called into action by the shock. The distance, $l$, is 12 feet, the weight $D$, per unit, is 1,560 lbs. For the 15-in. gun with 450 lb. projectile thrown by 100 lbs. of powder; or for the 12-in. rifle with 680 lb. projectile thrown by 70 lb. of powder, we should have for $\frac{P\,l^2}{2\,g}$, 14 millions and 12 millions of foot lbs. (respectively), while the co-efficient or first factor of (1) would be $\frac{1}{30}$ and $\frac{1}{240}$; and the resulting "available" energies 466,000 ft. lbs. and 600,000 ft. lbs.

The work of bending a rectangular beam up to rupture by a force applied at its middle is, (as may be deduced from theoretical considerations unnecessary here to develop) $\frac{1}{18}\,a\,b\,\frac{R^2\,l}{E}$ in which $a$ and $b$ are the sectional dimensions. $R$ the tensile strength, and $E$ the co-efficient of elasticity. Taking $R$ for average wrought iron, 53,000 lbs. per sq. inch, and E at a figure, corresponding to near approach to rupture, 1,450,000 lbs. per sq. inch; $a = 12$ in., $b = 15$ in., $l = 144$ in., we should get about 250,000 ft. lbs. as the work of the beams up to rupture. Allowing as much more for that of the portion (it is roughly assumed that that *half* of the plate immediately in front of the beam is effective) of the superimposed 12-in. plate, we should have a total of 500,000 ft. lbs. to oppose to the available energy of the shot, already estimated at from 460,000 to 600,000 ft. lbs. With methods of calculation so uncertain a very large margin should be found on the side of safety, whereas there is here a probable deficiency. Moreover, if the iron, instantaneously broken, will not yield the expected work, the deficiency will be yet greater.

70 lbs., is calculated to have struck with a velocity of 1,074 feet, and an energy of about 11,800,000 ft.-lbs.

The shot struck the (proper) left jamb-plate midway between the two posts, and about midway from top to bottom. It made an indentation 9 inches deep—threw off a large fragment from the back of the plate, and broke both of the posts, and fractured the plate nearly across the width.

Here the resistance of the two posts and the entire plate was called into play (since they were *all* bent to rupture), and their potential "work" should have been about 1,000,000 ft.-lbs.

The striking "energy of the projectile" (the initial velocity indicated by the chronoscope was 1,088 feet—less than due to the charge; striking velocity, 1,074 feet) was 11,800,000 ft.-lbs. The calculated available "energy of the projectile" in this case should have been (by formula of appended note) but about one-fortieth the above, in consequence of the inertia of the mass of the two posts, and the entire width of the cheek-plate being called into play, or about 300,000 ft.-lbs.; yet not only the two posts, but the plate itself, was completely ruptured.

In all the above instances, though the *striking energy* of the projectile was so enormously greater than the opposing energy, or "work," which the posts and plate could yield, yet, besides the indentation in the plate, little more than rupturing the posts was accomplished in any case; and to that extent, therefore, there is concurrence of facts, with theoretical considerations.

Although gauge rods had been placed behind the posts, as they stood in the target, to measure the deflection produced by the shock of the projectile, no satisfactory observations were obtained.

Hence it was impossible to estimate what amount of resistance (or opposing "work") the standards had really offered to bending or breaking. It was generally believed to have been much less than formula, founded upon assumed elastic extension of the fibres, would authorize us to assign them. Experienced iron manufacturers suggested that the highly crystalline appearance of the surfaces of fracture was caused by the instantaneousness of the rupture; others believed that it was common to *all* large forgings, and created during the slow cooling from welding heat; while still others attributed it to bad workmanship.

It was thought that it would be instructive to break one or more

of these beams under the slow pressure of a hydraulic press. For that purpose two were brought from Fort Monroe to the Brooklyn Navy Yard, one of which was the only sound one remaining in the case-mate shield; the other came from the "open embrasure" target.

The composition of the iron, and its conversion into bars for forging are thus described by the manufacturer:

* * * * * * * * * *

"The iron was made of the following brands of pig iron: Three-
"fourths Lake Superior charcoal, made by the Morgan Iron Company,
"at their old furnace near Marquette, Michigan. The blast, I suppose,
"ought to be called *warm.* The intensely hot blast now in use had not
"been introduced into that region at the time this iron was purchased,
"several years ago.

"The other one-fourth was of anthracite hot blast iron, made at the
"Donegal furnace, in the Juniata region, Penn. I adopted this mixture
"of metals as we found, after numerous trials of other irons, this to be
"the best for making blooms, of which to make galvanized iron. This
"requires a most superior iron, soft and malleable when cold. These
"qualities I judged were most desirable for armor plating.

* * * * * * * * * *

"The pig iron is converted into wrought iron by the usual method of
"puddling or boiling—from the furnace taken to the squeezers and
"formed into a lump, and then at the same heat rolled into bars of three-
"quarter inch to one inch in thickness, and four, six, and eight inches
"wide.

* * * * * * * * * *

"The bars thus formed were forged together into the beams under a
"four ton moving cylinder (Condie) hammer falling five feet nine
"inches."

* * * * * * * * * *

The diagram and table, pages 187 and 188, will give the facts of the first experiment. The following are the deductions therefrom:

The first recorded flexure of $\frac{1}{4}$ inch gives a calculated strain per square inch of the upper external fibres 36,792 lbs.; an elongation of the same of .00382; and a corresponding coefficient of elasticity of 9,558,600 lbs. (for inch units).

The seventh entry in the table shows a flexure of one inch under a pressure of 600 tons.

The corresponding tension of outer fibre is..... ...51,508 lbs.
" " extension of " " ".....0.0154 "
" " coefficient of elasticity is.....3,334,511 lbs.

The last entry but one shows a flexure of three inches under a pressure of 800 tons, for which we have :

Tension per square inch of outer fibres,.....68,450 lbs.
Extension..... " " ..... 0.0463 "
Corresponding coefficient of elasticity,.....1,482,000 "

The flexure of 3¼ inches produced rupture without any indication of increased pressure; and it will be observed that there are several stages in which the flexure thus increases. The press worked slowly—was frequently stopped (the whole time of experiment being 15 to 20 minutes), and when stopped the pressure became relaxed. On renewing it the flexure increased before the pressure gauge regained its lost elevation. Time had, *perhaps*, considerable to do in producing so great a flexure of the iron. Nevertheless, the "strength" of the iron is very great; and, for so large a beam, the extension of fibre is extraordinary.

The "permanent set" extended only 15 inches each way, from the place of fracture. At the limit of "set" the strain was equal to what would be produced at the middle point by a load of 400 tons, multiplied by $\frac{38.5-15}{38.5} = 242$ tons. This weight is about a mean between those required to produce deflexions of one-fourth and one-half an inch. It corresponds to a strain on the external fibres of 41,391 lbs., and an elongation of .005. But a remarkable feature in the "permanent set" is exhibited in the *cross section*. The base is permanently expanded one-half an inch, while the top is contracted or shortened one-third of an inch, by which the section of fracture has acquired a trapezoidal figure; a strong collateral proof of the ductility and toughness of the iron.

It must be borne in mind, however, that the above calculations suppose that, at the same moment, the coefficient of elasticity is uniform throughout the beam. We see, however, that the coefficient rapidly diminishes as the extension increases, and hence it must be very much less in the more extended outer fibres than in those near the neutral

axis. Moreover, it is probable that it does *not* so decrease for increased compression; and hence the neutral axis will fall below the middle of the beam. This last effect is indicated, too, by the change in the section; the area of the portion below the middle line becoming about one twenty-fourth larger than that above it. The above figures for breaking tension must, from all these causes, be somewhat too high.

On the 25th of May the second beam was subjected to the same test. It was manufactured about six months earlier than the one first described, but there is no known difference in the material or process of manufacture. The statement, page 189, herewith, will give the particulars of the experiment. Though the breaking pressure proved to be identically the same as before, the flexure was but one inch instead of $3\frac{1}{4}$ inches. That is to say, the tensile strength was as before, 68,450 lbs. per square inch; but this corresponded to an "elongation" of fibre but 0.0154, while the coefficient of elasticity was 5,446,000 instead of 3,334,511 lbs., the coefficient furnished by a corresponding extension in the first beam. No "permanent set" either in figure or cross section was observed. In this case there was no stoppage of the force pump, and the power was applied as rapidly as possible, the rupture taking place in about $2\frac{1}{2}$ minutes.

In all cases, whether the beams were broken by the instantaneous shock of the projectile, or by the comparatively slowly applied pressure of the press, the fracture was throughout highly crystalline. I do not think that there is any decided distinction between the results of the two processes. In the last beam broken the cleavage surface of the crystals was larger and the fracture more ragged than in the first. Around the outer margins of both, the fractured surfaces were much finer grained (approximating in the first beam to the appearance of *very* coarse sand-paper) than at the central portions. The largest cleavage surfaces may be one-eighth to one-fourth square inch in area—though such are rare. The second beam, more highly crystalline than the first, had less ductility (*i. e.*, was more brittle), yet its breaking strain was not impaired.

As the foregoing calculations could not, for the reasons stated, be implicitly relied on, it was important to determine the tensile strength by direct experiment. Two specimens were taken from each of the beams—one of which was heated and hammered, and drawn down to

proper size—the others tested just as they came from the beam. (These last were taken from the central and most crystalline portion of the forgings.) The results are as follows:

| | Tensile Strength |
|---|---|
| No. 1. First beam, reworked specimen | 63.413 lbs. |
| No. 2. Second beam " " | 67.846 " |
| No. 3. First beam, unworked " | 53.953 " |
| No. 4. Second beam " " | 57.786 " |

The fracture of No. 1 was what is called "fibrous," that is fine-grained and dark, when looked at directly, but lustrous under certain lights, and what is usually considered as indicating a superior iron.

The central part of No. 2 (say about one-third) had the same appearance as No. 1, though inferior; a'l the rest, say two-thirds of the surface was highly crystalline, and not finer-grained than *some parts* of the fracture of the original beam.

Of No. 3 the fracture was very similar to that of No. 1, though less lustrous.

The fracture of No. 4 exhibited over a segment comprising about one-third of the circular area, a fine-grained fracture, but darker and destitute of lustre; the rest of the surface was highly crystalline, yet less coarsely grained, if there was a difference, than the crystalline parts of No. 3.

It is to be observed that the real tensile strength of the iron *in the beam* (as given in Nos. 3 and 4) was in one case 20, in the other 15 per cent. less than that deduced from calculation; that the process of reworking gives about an equal increment in the two cases. The difference in the two beams may be owing to variations in the character of pig-iron coming from the same sources, or from varying time and heat in the forgings.

The tensile strength exhibited by these beams was above the *average* for wrought iron in bars, while the reworked specimens are equal to the average of a large number of specimens of Burden iron, and approach in strength the best irons known, as will be seen from the following figures:

Major Wade gives (1845) strength of different irons thus:

| | | |
|---|---|---|
| Russian iron (in flat bars) | 62.644 lbs. | per. sq. inch. |
| Bankes' (English) | 56.532 " | " |
| Low Moor " | 56.103 " | " |
| Bridgewater (American) iron | 48.488 " | " |
| " " " | 49.338 " | " |

Salisbury iron is given by Prof. W. R. Johnston

at..... 58.009 lbs. per sq. inch.

And charcoal refined Lake Superior at..... 89.582 " "

The Ordnance Manual gives for—

Bar iron..... 57.000 lbs. per sq. inch.

Salisbury iron..... 57.000 " "

Swedish iron..... ... 72.000 " "

Kirkaldy says: "The breaking strain per sq. inch of wrought iron is "generally stated to be about 25 tons for bars and 20 tons for plates. "This corresponds very nearly with the writer's experiments, of which "the following table presents a condensed summary:

| | Lbs. | Lbs. | Lbs. |
|---|---|---|---|
| "188 bars, rolled..... | highest, 68.848; | lowest, 44.584; | mean 57.555 |
| " 72 angle-iron, etc..... | " 63.715; | " 37.909; | " 54.729 |
| "167 plates, lengthways.. | " 62.544; | " 37.474; | " 50.737 |
| "160 " crossways... | " 60.756; | " 32.450; | " 46.171." |

The extension, especially of the first beam (one twentieth, nearly), though far beneath that sometimes exhibited by small rods or wires, is very remarkable, when the dimensions of the forgings and the highly crystalline structure of the iron is considered.

It is highly probable that so great extension of fibre as these experiments developed did not take place in the beams ruptured by the firings. Though identical with the experimental beams in composition and manner of fabric, not the slightest trace of "set," so strikingly exhibited by the first beam, could be observed in them. That the forgings were excellent may be inferred from the absence of appearances of seams or flaws in the fractures, and from the rupture occurring exactly at the middle point. The engineers and master mechanics of the Navy Yard, and other experienced operators in iron, regarded them as "of most excellent quality of "workmanship, having the clearest and most solid appearance of any bars "they had seen."

The results show neither high tensile strength nor a considerable ductility to be incompatible with the process of "forging" in large masses; and that iron of a highly crystalline structure (the usual result of such forging) may possess these qualities; that, in common with iron so pre-

pared as to possess the maximum of ductility, it does not exhibit that quality to its full extent when the rupturing shock is instantaneous.

Hence the iron supports of shields should be of such a character (*e. g.* built-up beams) that the necessary yielding may take place by *warping* rather then extension of fibre; or, on the other hand, should be such as to involve *no extension whatever*—the target, by means of arched backing or something of the kind, being made perfectly rigid and the shot made to expend *all* its work, instead of at least nine-tenths (as it inevitably must do) *upon the indentation.*

On the 14th of August a beam of the same dimensions, cast vertically, from the same pig irons in the same proportions, and allowed to remain in the mould until thoroughly cool, was broken in the press.

The results were as follows:

Flexure $\frac{1}{4}$ inch, ..... Pressure, 183 tons.
" $\frac{3}{8}$ " ..... " 276 "

At which flexure the beam broke.

From whence by calculation we should get for a flexure of $\frac{1}{4}$ inch:
Tension per sq. inch of outer fibres..... 15.640 lbs.
Extension of fibre..... 00.382 "
And for a flexure of $\frac{3}{8}$ inch:
Tension of outer fibre (that of rupture)..... 23.615 lbs.
Extension of fibre ..... 00.53 "

A specimen of iron from this beam was tested for tensile strength and found to have 16.067 lbs. or about 33 per cent. less than deduced above.

It was believed that better results might be obtained, and the iron was remelted in a reverberatory furnace, four and a half hours being occupied in the melting, the casting remaining three days in the mould.

This recast beam broke with a pressure of 384 tons, with a flexure of $\frac{5}{16}$ inch, which would give a calculated tensile strength of 32.850 lbs. A specimen of the iron of this beam was then tested for tensile strength; the result was 17,140 lbs. per sq. inch, or not much over 50 per cent. of that which was obtained by calculation based on transverse strength.

A remark is here necessary in explanation of preceding calculations. The Ordnance Manual, p. 436, gives the following expression (to be found in all works on the strength of materials) for the breaking weight of a rectangular beam supported at both ends and loaded in the middle:

$$W = 4\,S\frac{bd^2}{\quad}$$

in which $W$ is the required weight, $l$ the distance between the supports, $b$ and $d$ the horizontal and vertical dimensions of the section. If the law of elasticity upon which the theory is based held good, that is if the "co-efficient of elasticity" remained constant for all degrees of extension and was identically the same *for compression*, the co-efficient $S$ would be *one-sixth the tensile strength of the material*. As it is the outer and upper fibres only which are extended to rupture when the beam gives way, we should therefore have, calling T the tensile strength of those fibres, or of the material,

$$T = \frac{3}{2} W \frac{l}{bd^2}$$

More generally if W' is any weight (*less* than the breaking weight W), supported at the middle, and R the tensile strain thus produced upon the outer fibres, we should have

$$R = \frac{3}{2} W' \frac{l}{bd^2}$$

It is thus that I have calculated the "tension of outer fibre" for different stages of the experiments—there being, in fact, no other way. I have already remarked upon the inaccuracy of this calculation when it is applied to great extensions or to strains approaching rupture. In fact, the assumptions of constancy in the coefficient of elasticity and of its identity for compression and extension, however convenient, are well known to be in opposition to the results of experiment. In Morin's Table (p. 8, "Resistance de Materiaux") the coefficient of extension for wrought iron is, at the state approaching rupture, but about $\frac{1}{2}$ of what it is at the beginning.* On the other hand, the coefficients for compression and extension are not identical. Hence, as the fibres along the section of rupture are in all stages of extension, from a maximum at the upper fibre down to zero at the neutral axis, and thence have increasing degrees of compression to the lower surface, such formula can give but inaccurate results. Nor can they approach to much accuracy when the coefficient, S, as applied to breaking strains, is determined by experiments; for the results are extremely variable, depending on the character of the iron and the form of the section. In the three instances

* The extreme extension in this Table does not exceed or even equal that which was found for the outer fibres of the first beam broken—viz., .0463.

given in the Ordnance Manual for "cast-iron," S varies from $\frac{1}{3}$d to $\frac{2}{5}$ths the given tensile strength of the material. In the single case given for "bar iron" it is but little over $\frac{1}{4}$th of the corresponding tensile strength.

In the case of the forged iron beams experimented upon, the resulting value of S would be, for the first a little less, for the second a little greater, than one-fifth the strength which direct experiments proved to belong to the "unworked" iron of the beams.

In the case of the castings, in the first case S would approximate to $\frac{1}{4}$th, in the second to $\frac{1}{3}$d the real tensile strength of the iron. In all these cases the ratio of these fractions to $\frac{1}{6}$th is the ratio by which the *calculated* exceed the true tensile strengths, as afterwards determined by direct experiment. The calculated "extension of fibre" does not err, necessarily, in the same direction. It does not, probably, exceed the real extension, and must, indeed, fall short of it if the neutral axis, through inequality in compression and extension, is lower than the assumed central position, as it probably is in all cases in which S exceeds $\frac{1}{6}$th T.

The average "tenacity" of cast-iron gun-metal, prior to 1841, is given at ..... 23,638 per square inch.
In 1851, it was ..... 37,774 " " "

The mean tensile strength of the iron of the two 10-inch guns which endured 2,540 rounds each, was 26,038 lbs.

Although the *cast-iron* of these beams proves comparatively weak, the extensibility of the metal appears to be much greater than that of the gun-metal tested by General Rodman (p. 159, Experiments on Metals, etc.).

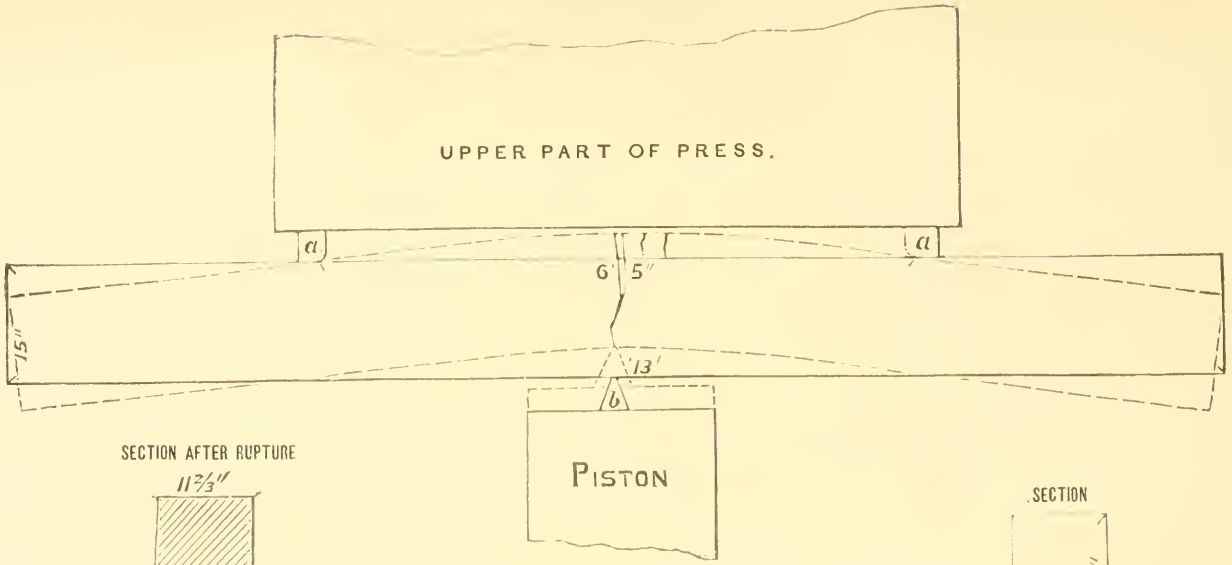
The fracture of the iron in the beam at first cast exhibited a leaden gray color and a crystalline structure quite uniform, but quite as coarse and *apparently* less close than that of Lake Superior charcoal pig-iron; the fracture of the re-cast beam showed greater compactness. The particular composition of iron used in these beams appears to be quite inferior as cast-iron to what it is when wrought.

Limited in scope as are these experiments, I think they furnish presumptive evidence of the superiority of forged wrought iron, in large masses, over cast-iron, for ordinary transversal strains and for the endurance of shocks. The universal use of wrought iron for shafts of

steamships, etc., is in accordance with this conclusion ; and if such observations as we could make at the firings furnish no proof that the elastic forces of the iron were fully called into play, yet the subsequent experiments go to show that neither the process of forging nor the crystalline structure which results from it are *necessarily* destructive of ductility and tenacity. If it appears, indeed, that even the most ductile and tenacious wrought iron is, like cast-iron, *brittle* under the action of instantaneous applied rupturing strains, yet the presumption of superiority is certainly in favor of that material which possesses the above qualities in the highest degree.

The press, used under the direction of the able Naval Constructor, Mr. B. F. Delano, was one made in England, and set up in the Brooklyn Navy Yard, for the purpose of bending armor plates. Its gauge was graduated to 2,000 tons (of 2,000 lbs.), and the accuracy of its indications was thoroughly tested.

In relation to forged iron in masses of large dimensions (such as shafts of steam-ships, rolling-mills, etc.,) there is great diversity of opinion, and little experimental knowledge. That they frequently break is notorious. If it happens that a flaw in the forging is found, as is sometimes the case, the rupture is of course satisfactorily *explained*, even if it casts doubt upon the reliability of the forging process. But quite frequently no flaw is found (and the means and processes are so thoroughly perfected at the present day that there is no excuse for their occurring), while the sharply defined and highly crystalline fracture, which is invariably observed, is usually considered an indication of dangerous brittleness. The various explanations already mentioned as having been applied to the fracture, by gun-shot, of the beams in the target, are freely offered. Inconsistent with each other, experimental observation is almost wholly wanting to test their validity. Hence the experiments herein recorded, limited as they are, may prove of some value.




*a a*, bearings of steel. *b*, piece of steel 1″ wide on top.

Scale $\frac{1}{2}'' = 1$ foot.

NOTES ON THE BREAKING OF THE IRON BEAMS IN THE HYDRAULIC PRESS IN THE BROOKLYN NAVY YARD, BY BRIG.-GEN. C. B. REESE, UNITED STATES CORPS OF ENGINEERS.

The following Table shows the flexure of the first beam at different pressures:

| Flexure in inches. | Tons of 2,000 lbs. pressure. | |
|---|---|---|
| $\frac{1}{4}$ | 430 | |
| $\frac{3}{8}$ | 500 | |
| $\frac{1}{2}$ | 553 | |
| $\frac{5}{8}$ | 584 | |
| $\frac{3}{4}$ | 584 | |
| $\frac{7}{8}$ | 597 | |
| 1 | 599.6 | |
| $1\frac{1}{8}$ | 645 | |
| $1\frac{1}{4}$ | 645.8 | Two small cracks noticed on the face of the beam, at top, to right of fulcrum. |
| $1\frac{3}{8}$ | 645.8 | |
| $1\frac{1}{2}$ | 661 | |
| $1\frac{5}{8}$ | 676 | |
| $1\frac{3}{4}$ | 676 | |
| $1\frac{7}{8}$ | 692 | |
| $1\frac{5}{10}$ | 707 | |
| 2 | 707 | |
| $2\frac{1}{8}$ | 738 | |
| $2\frac{1}{4}$ | 753 | |
| $2\frac{1}{2}$ | 769 | |
| $2\frac{3}{4}$ | 784 | |
| 3 | 799 | |
| $3\frac{1}{8}$ | 799.8 | Broke across, as shown in sketch, the fracture being highly crystalline—the crystals being largest in the centre. |

The following Table shows the flexure of the second beam at different pressures:

| Flexure in inches. | Tons pressure (of 2,000 lbs.) | |
|---|---|---|
| $\frac{1}{8}$ | 615 | |
| $\frac{1}{4}$ | 707 | |
| $\frac{3}{4}$ | 767 | |
| 1 (short | 799 | Broke across, as shown in sketch; the fracture being highly crystalline. |

In this experiment the pressure was applied as rapidly as possible, and the beam broke in about 2½ minutes after commencing the experiment.

The breaking of the beam, on the 13th instant, probably occupied 15 or 20 minutes *at least*.

XV.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## THE MANUFACTURE OF PIG-IRON.

A paper read before the Society, December 1, 1869, by E. N. K. Talcott, Civil Engineer, Member of the Society.

In view of the magnitude of the iron trade, the varied and important uses of iron and its absolute necessity in all engineering operations, the following data in relation to the manufacture of pig-iron have been gathered with the hope that they may prove of interest. This paper presents:

I. A brief statement of the iron ore bearing localities of the United States.

II. A brief statement in relation to the production of pig-iron in the United States.

III. The most important improvements in the process of its manufacture.

IV. A few general remarks bearing upon these points.

### I.—The Iron Ore bearing Localities of the United States.

Iron ore, the *sine qua non* of the iron master, is found in great abundance in most of the States, and in many of them in close proximity to

coal and limestone, both of which are also indispensable. For many years Pennsylvania, New York, Ohio, and New Jersey stood first in its production, but of late, valuable deposits have been opened and worked in other places, and the most recent discoveries promise to put these localities in the shade. At the present time, however, Pennsylvania undoubtedly stands pre-eminent in the advantageous distribution of materials—the immediate contiguity of the coal, ore, and limestone, being such as to reduce the transportation of the raw materials to the minimum. In ores she is especially rich, having the magnetic oxide in Bucks, Lehigh, Lebanon, and Huntingdon counties; red oxide in Montour, Columbia, and Blair counties; brown hematite in the Lehigh, Saucon, and adjoining valleys, in great abundance; fossil in Montour, Columbia, Union, Huntingdon, Blair, and Bedford counties; and argillaceous in Schuylkill, Lawrence, Cambria, Mercer, Clarion, Butler, and other counties. Her immense coal deposits, both of anthracite and bituminous, furnish an abundance of fuel for smelting these ores.

In New York we also find a great variety of ores. Along the line of the Harlem Railroad, in Columbia and Dutchess counties, are large deposits of a superior quality of brown hematite, including the famous Salisbury ores on or near the Hudson River, and in the Lake Champlain region large veins of magnetic oxide exist (the production of the Lake Champlain region alone in 1868, being 230,000 gross tons); in Lawrence, Jefferson, and Oneida counties, red oxide is found; in Oneida and Ulster counties, fossil ore, and in St. Lawrence county, bog ore. These ores, with the exception of the Lake Champlain ore, some of which goes as far west as Pittsburg, are mostly smelted in the furnaces on the Hudson River and other localities within the State, the fuel used being mostly anthracite coal from Pennsylvania.

In New Jersey magnetic oxide occurs in large quantities in Morris, Sussex, Passaic, and Warren counties, the principal portion of which is exported to Pennsylvania for mixture with their leaner ores, the amount so exported in 1868 being 360,000 gross tons. In Warren county red oxide and brown hematite also exist, and in Sussex county, brown hematite, and bog ores, and franklinite.

The Lake Superior region of Michigan produces specular ore and magnetic oxide in almost unlimited quantities, mostly for exportation. The growth of this locality has been quite remarkable, and as reliable

figures respecting it are accessible they are appended. Commencing in 1856, they are as follows:

*Shipments of Iron Ore from Marquette County, Michigan.*

| | | | |
|---|---|---|---|
| In 1856..... | 7,000 gross tons. | In 1863..... | 185,257 gross tons. |
| 1857..... | 21,000 " " | 1864..... | 235,122 " " |
| 1858..... | 31,035 " " | 1865..... | 195,256 " " |
| 1859..... | 62,679 " " | 1866..... | 296,872 " " |
| 1860..... | 116,998 " " | 1867..... | 469,320 " " |
| 1861..... | 45,430 " " | 1868..... | 507,813 " " |
| 1862..... | 115,721 " " | | |

In 1869 the shipments will probably exceed 600,000 gross tons.

In Wisconsin we find both the magnetic and red oxides in considerable quantities; in Ohio, Massachusetts, and Connecticut, brown hematite of a superior quality, and in Vermont, New Hampshire, Oregon, and California, magnetic oxide in greater or less amounts.

The opening up of the Southern States, consequent upon the abolition of slavery, and the influx of Northern capital, has developed a mineral wealth which promises to rival the richest of already available localities. In Tennessee the deposits are rich and extensive. In Alabama brown hematite and fossil ores of more than ordinary richness, and very easily mined, abound; and from the advantageous distribution of coal, ore, and limestone, this State bids fair to become the Cleveland district of this country. With capital and enterprise to develop it, the entire consumption of the Southern States can easily be supplied from this region alone. Iron ore is also found to some extent in North and South Carolina, Georgia, Missouri, and Virginia. The Pilot Knob and Iron Mountain deposits of Missouri need only to be mentioned to be recognized.

## II.—The Production of Pig-Iron.

In the manufacture of pig-iron, Pennsylvania also stands foremost, having produced in the year 1868, nearly 58 per cent. of the entire make of the United States. Her abundant deposits of coal, and her widely ex-

tended railroads and canals, give her advantages as yet possessed by no other State. The valley of the Lehigh, from Mauch Chunk to Easton, has nearly one furnace for every mile of distance. The valley of the Schuylkill, from Reading to Philadelphia, is lighted by furnace fires, and in the western part of the State the city of Pittsburg is one vast iron manufactory. Besides these three principal localities, pig-iron is made in greater or less quantities in almost every part of the State.

Ohio stands next to Pennsylvania as an iron-producing State, having, in 1868, made about 15 per cent. of the iron made in this country. The whole of the eastern and some of the southern parts of the State abound in furnaces. Large quantities of Lake Superior ore are used in conjunction with native ores, and coal and limestone abound in the State.

New York produces about 12 per cent. of the make of pig-iron. The Hudson River is already the seat of a large proportion of this manufacture, and, from its favorable situation for the supply of materials at a cheap rate of transportation, must continue to be the principal iron locality of the State. Furnaces exist, however, at various points in the interior and western parts of the State.

The remaining 15 per cent. of the pig-iron production is principally divided between New Jersey, Michigan, Connecticut, and Massachusetts, though some of the other States produce small quantities. Herewith is given a tabular statement of the production of pig-iron in the United States, from 1810 to 1868, which is believed to be quite reliable:

| YEAR. | Production in Gross Tons. | Increase of Production per cent. | Annual Increase of Production per cent. | Annual Increase of Population per cent. |
|---|---|---|---|---|
| 1810 | 54,000 | | | |
| 1828 | 130,000 | 140 % in 18 yrs. | | |
| 1830 | 165,000 | 211.11 " 20 " | 10 50 % | 3 88 % |
| 1832 | 200,000 | 21 " 2 " | | |
| 1840 | 347,000 | 110.3 " 10 " | 11. % | 3.26 % |
| 1845 | 486,000 | 49 " 5 " | | |
| 1850 | 564,755 | 62.7 " 10 " | 6.27 % | 3.58 % |
| 1855 | 754,178 | 32.7 " 5 " | | |
| 1860 | 913,770 | 61.8 " 10 " | 6.18 % | 3.54 % |
| 1864 | 1,135,497 | 24.26 " 4 " | 6.06 % | 3. % |
| 1866 | 1,334,704 | 46. " 6 " | 7 66 % | 3. % |
| 1867 | 1,447,771 | 58.4 " 7 " | 8.46 % | |
| 1868 | 1,603,000 | 75.42 " 8 " | 10.72 % | |

## III.—Improvements in the Processes of the Manufacture of Pig-Iron.

### *a.—Size and Shape of Blast Furnaces.*

From the first manufacture of pig-iron to the present time, the general form of the blast furnace has remained the same, consisting of a vertical chamber or shaft, circular in form, but widening from the bottom upwards and from the top downwards. The shape most generally adopted in this country consists, first of a crucible at the bottom, the sides of which are perpendicular for from 6 to 8 feet; thence the furnace widens out at an angle (called the angle of the bosh) of from 60° to 70° until the required width is reached. This widest point is known as the bosh. Thence a slight reduction of size is carried to the flues which take off the waste gases, from whence to the tunnel head or mouth the size decreases more rapidly until the required diameter is reached. The sizes and proportions of different furnaces are so varied that it is impossible to estab-

lish any positive rules for them. The furnaces in the Lehigh valley are as follows:

| | | | | | | |
|---|---|---|---|---|---|---|
| Crucible | from | 5 | to | 10 | feet | in diameter. |
| Bosh, | " | 10 | " | 20 | " | " |
| At the flues, | " | 8 | " | 14 | " | " |
| Funnel head, | " | 5 | " | 12 | " | " |
| Total height, | " | 40 | " | 73 | " | " |

See Note I.

Various improvements upon the general outline have been adopted, as carrying the lining perpendicular from the bosh partly up to the flues, or dispensing with all angles, and making the interior a combination of curved lines, but the same general form is retained. The tendency at the present is to increase both the height of the furnace and the size of the bosh. In England, high furnaces with large boshes have been largely adopted, and are giving some remarkable results. In the valley of the Lehigh, the average product of furnaces 55 feet high and 18 feet boshes is 225 tons of No. 1 pig metal per week, with a consumption of about two tons of coal to one ton of pig-iron. The Norton furnaces, near Stockton-on-Tees, England, which are 85 feet in height and 25 feet boshes, produce 530 tons of iron weekly, using about one ton of coke to one ton of iron. The Ferry Hill furnaces, England, are 103.5 feet high, and 27.5 feet boshes, and produce weekly 600 tons of iron with an average consumption of 15½ cwt. of coke to one ton of iron. The smaller furnaces in England use from 1 ton 17 cwt. to 2 tons of coke to 1 ton of iron. In addition to the increase in production and decrease in consumption of coal which seems to be the result of these large furnaces, the quality of iron seems to have been improved thereby. The iron used in the manufacture of Bessemer steel is principally made in these large furnaces. It would seem to be well worth the while of the iron-masters of this country to study carefully the results of these furnaces, with a view to an increase in the size of ours. Indeed, some advance has already been made in that direction, one of the furnaces at Glendon, Penn., in the Lehigh valley, being 73 feet high and 18 feet boshes, and one at Stanhope, New Jersey, yet unfinished, is to be 85 feet high and 22 feet boshes. But the materials used here differ so much from those in England that experiments in this direction must necessarily be conducted with the utmost caution, to avoid disaster.

# NOTE I. SECTIONS OF BLAST FURNACES.




Port Oram Iron Co., Port Oram, N. J. as originally designed by E. M. R. Talcott, C. E.

*b.—Hot Blast.*

Perhaps the most important of all the improvements in the iron manufacture during the 50 years last past, is the use of heated instead of cold air for the blast. This invention was first applied in 1830, by Mr. James Beaumont Neilson, at the Clyde Iron Works, and, although the temperature was only raised to 300° F., produced a saving of nearly 33⅓ per cent. in the consumption of coal. The first apparatus was exceedingly rude and simple, consisting of a boiler iron chamber 4 feet by 3 feet by 2 feet, the air entering at one end and leaving at the other. This being soon destroyed, cast-iron was substituted, the chamber giving about 55 square feet of heating surface. Next Mr. Neilson substituted a horizontal arrangement of cast-iron pipes with a heating surface of 240 square feet for each tuyere, producing a temperature of 600° F. This oven having given much annoyance from leakage, various improvements have been made thereon, until the present form has been reached, which is of cast-iron, and consists of a series of bed pipes, cast with sockets upon them, in which (in some ovens with both legs resting on the same, and in others on different bed pipes) stand upright pipes of the shape of an inverted U connected with the bed pipe by means of a rust cement joint. These U pipes are exposed to the fire, the bed pipes being protected by a casing of fire brick, and the air, entering the bed pipes, circulates through the uprights and is heated during its passage to a temperature varying frm 600° to 1000° F., according to the amount of heating surface employed. The ovens are almost universally heated by the waste gases of the furnace, and in most of them the burning gas is brought into direct contact with the pipes, being generally introduced from below by flues leading up between the bed pipes, although, in the improved form of the Thomas Hot Blast, the fire is introduced from above, impinging directly upon the tops of the pipes. The action of the fire upon these pipes, however, at the extreme heat maintained in the ovens, causes them to burn out, and necessitates frequent renewals, which are both troublesome and expensive. Mr. John Player, formerly of the Norton Furnaces, England, but now a resident of Philadelphia, claims to have obviated this difficulty to a great extent, by employing a large combustion chamber underneath the oven, with deep and very narrow flues up into the pipe chamber, through which the resultant heat of the combustion of the gas, and but very little of the fire, comes in

contact with the pipes, while the same or greater heat is obtained as under the old plan. So far as this is in use in this country it gives tolerable satisfaction, although I have been unable to learn that the excessive temperature of 1200° F. which he claims can be produced, has ever been reached.

An entirely new style of oven has lately been patented by Mr. Thomas Whitwell, of the Thornby Iron Works, Stockton, England, consisting of a cast-iron air-tight casing, 22 feet diameter, and 20 feet high, lined with 18 inches of fire-brick, and the interior divided by fire-brick walls into compartments of different sizes, largest at the hot end. The gas enters the oven at the hot end, where it is lighted, and passing through the compartments, burning as it goes, escapes at the cold end into the smoke-stack, the fire-brick absorbing and retaining the greater part of the heat generated by the combustion. After the brick has mostly become red hot the gas is shut off and the blast admitted at the cold end of the oven, passing through the oven in the reverse direction from the gas, and by its passage over the brick becoming heated to a red heat, and in this condition passing into the furnace. These stoves are built in pairs, being used alternately for the admission of gas and air. It is claimed that one of these stoves will supply sufficient heat to raise 8,000 cubic feet of air per minute to a red heat for 3 hours, and that it can be reheated in 1½ hours, while the cost is no greater than the ordinary cast-iron stoves. They possess the advantage of simplicity of construction, slow fouling from dust, facility for cleaning, and durability. At the Consett Iron Works, England, where they are in use, it is stated that zinc is melted at the plug hole of the tuyere, in 2½ seconds, and that the tuyere pipes are red hot in open day, the temperature being estimated to have been as high as 1,500° F. The use of heated air for the blast has been found to result in a decreased consumption of coal, and thus far the hotter the blast the greater this decrease. Hence the point to be attained is to produce the greatest heat in the simplest and most economical manner; in which points this oven seems to excel.

### *c. Utilization of Waste Gases.*

It was formerly the custom to allow the gases generated in the blast furnace to escape and burn in the air at the tunnel head. In the year 1832, Mr. Moses Teague, of England, patented a device for collecting and

using these gases, which was first applied by Mr. Jas. Palmer Budd, at the Ystalefera Works, to the heating of hot-blast stoves. He, however, did not burn the gases, but simply passed them through the ovens in the heated state in which they issued from the furnace. Since that time various devices have been used for the employment of the gases, and now almost every furnace in the country not only heats their blast, but generates the steam for their engines by their combustion. They are taken out of the furnace at the level of the tunnel head, or from that down to 10 or 12 feet below, in flues constructed in the lining of the furnace, and are conducted in flues or pipes to the position where it is desired to use them, where they are mixed with atmospheric air and burned. In this way, what was formerly allowed to waste into the air produces all the heat required for both blast and steam.

*d. Blowing Engines.*

When it is taken into consideration that for every ton of solid material used in making a ton of pig-iron, 3 tons of air in the shape of blast must be supplied, it will at once be seen that the apparatus for producing this blast is of the utmost importance. The blast engine may be said to be the lungs of the furnace; cripple it and the furnace dies. As the blast is delivered to the furnace at a pressure varying from 3 to 8 lbs. per square inch, the machine must be strong and substantial. As the quantity to be delivered is large, it must be proportionally large; and as the power required is great, it must be applied as economically as possible. But comparatively few furnaces being able to use water as their motive power, steam engines are generally used for this purpose. The steam is generated by the waste gases. Generally the boilers are elevated on masonry piers, nearly to a level with the flues of the furnace. Latterly, however, they have been placed on the ground, and the gas drawn down to them by means of a powerful draft, and with great success. This dispenses with a great deal of expensive masonry. The engines are of varied construction, but all involve an ordinary steam cylinder attached in some way to a blowing cylinder, each head of which is made with a number of openings closed by leather flap-valves, one half of which open inwards and the other half outwards, thus forming in effect a bellows. The forms of engines most used are beam engines with the steam and blowing cylinders at opposite ends of the beam. Vertical engines with

the cylinders side by side and the piston rods both connected to one cross head, or with the blowing cylinder directly over the steam cylinder, and horizontal engines with two blowing cylinders driven by one steam cylinder through the interposition of gearing, or with one blowing cylinder on a line with the steam cylinder and both pistons on one rod running through both ends of both cylinders. All of these engines involve heavy fly-wheels to insure a steady motion. A new vertical engine has lately been built, with the steam cylinder over the blowing cylinder, which dispenses entirely with fly-wheels, is so entirely novel in its construction that a print of it is annexed, which will give a much better idea of it than a description. One of these engines is now at work at Niles, Ohio, blowing a furnace 45 ft. high, with 10 ft. boshes. All of these styles of engine have their advocates, and all possess some advantages and disadvantages. For reliability, endurance, and satisfactory results, however, the beam engine seems, thus far, the favorite. To give a better idea of the sizes of the engines used for this purpose, some figures in relation to them are given below.

| Where Used. | Diameter of Steam Cylinder. | Diameter of Blowing Cylinder. | Length of Stroke. | Number and kind of Engines | Number of Furnaces. |
|---|---|---|---|---|---|
| Thomas Iron Works, Hokendauqua, Pa. | 66 ins. | 108 ins. | 10 ft. | 2 beam engines | 4 |
| | 56 " | 90 " | 9 " | 2 beam " | |
| Allentown Iron Works, Allentown, Pa. | 10 " | 84 " | 7½ " | 1 vertical " | 4 |
| | 48 " | 84 " | 7½ " | 1 beam " | |
| | 40 " | 84 " | 7½ " | 2 beam " | |
| Carbon Iron Works, Perryville, Pa. | 36 " | 84 " | 7 " | 1 vertical " | 2 |
| | 50 " | 84 " | 7 " | 1 vertical " | |
| Burden's Iron Works, Troy, N. Y. | 40 " | 96 " | 7 " | 2 horizontal " | 2 |
| Boonton Iron Works, Boonton, N. J. | 40 " | 90 " | 7 " | 1 horizontal " | 2 |
| | 40 " | 84 " | 7½ " | 1 vertical " | |
| Port Oram Iron Works, Port Oram, N. J. | 40 " | 84 " | 7½ " | 1 vertical " | 1 |

*1.—Construction of Furnace Stacks.*

The great majority of furnace stacks are massive constructions of stone masonry of a square base with an arch on each face for tuyeres and casting purposes, surmounted by a brick gas chamber and tunnel head. The stone work is tied together by heavy wrought-iron binders running through it in all directions. Where stone is abundant this is a preferable form, from its cheapness, durability, and heat-retaining qualities. These stacks are not built of solid masonry, but have an outside and inside wall laid in mortar, with the intermediate space filled with loose stone. In regions where good building stone are scarce, other materials have been employed. Of these, brick and boiler iron are the most common. The brick stacks are generally circular in form and encircled by wrought-iron bands at intervals of about 2 feet. These stacks stand well for awhile, but are liable to crack badly with the heat, and burn out. They also waste considerable heat by radiation. The iron stacks consist of a shell of boiler iron supported upon cast-iron columns, and give excellent satisfaction. Their cost is very nearly the same as stone, and they possess an advantage in being quickly erected, and giving ready access to the base of the furnace on its entire circumference. They are not as economical of heat as the stone stacks, but are being adopted to a very considerable extent.

* See Note II., p. 202.

IV.—General Remarks.

From these data in relation to the manufacture of iron, you may perhaps form some idea of its present condition and importance. When it is remembered that for each ton of pig metal produced per annum, a plant of $20 is required as a permanent investment, besides a working capital of from $5 to $10 per ton, it will be readily seen what a large amount of capital is already invested in this branch of industry in this country, amounting, it is believed, in the year 1868, to nearly fifty millions of dollars. The new and varied uses of iron, and the amount required annually to repair the wear and tear of that already in use, give promise of greater demands in the future. Railroads are multiplying continually, for which must be supplied not only rails, but rolling stock, bridges, depots, and other equipments, into the construction of all of which iron

enters largely. Iron buildings are taking the place of stone and brick in all of our large cities; our ships are no longer of oak, but iron vessels crowd out the old wooden ones, until even the rigging is of wire rope; the axles of our wagons are of iron—in fact, so cheap and abundant has this staple become that it is produced in almost every conceivable form, and for almost every conceivable purpose. With a protective tariff sufficient to insure a reasonable profit upon its manufacture, it is difficult to foretell the production ten years hence. Certainly, as the unoccupied territory fills up, as wealth increases, and civilization advances, this article, which has now become one of the necessaries of life, must continue to be more and more in demand; to supply which, new localities must be developed and new works erected. And as the country grows older, and labor and capital both become more abundant, the expense of production must be reduced, until it will not be at all remarkable to find American iron competing with that of other nations in all the markets of the world.

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*Note II.—Some experiments made by the writer at blast furnaces in the Lehigh valley in reference to the loss of heat by radiation through the stack, gave the following results, the thermometer in the open air standing at 20° F.:

On the outside of stone stacks varying from 6 feet to 10 feet in thickness of masonry, from 60° to 90° F.

Brick stacks 30 inch wall, from 120° to 190° F.

No experiments were made with iron stacks.

In the boiler rooms the outside of a brick wall 24 inches thick gave as high as 212° F.

Hot blast oven walls 18 inches thick gave as high as 220° F.

From these facts it will be seen that the saving of radiated heat about a blast furnace is a problem which will bear study with a view to economizing in fuel by the use of the heat so wasted.

XVI.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

## TRANSACTIONS.

### EXPERIMENTS FOR MAKING BRICK MASONRY IMPERVIOUS TO WATER, TRIED ON THE WALLS OF THE BACK BAYS OF THE GATE-HOUSES OF THE NEW CROTON RESERVOIR IN NEW YORK, AND ON THE BRICK ARCH OF HIGH BRIDGE, IN 1863.

A Paper read before the Society May 4, 1870, by William L. Dearborn, Civil Engineer, Member of the Society.

The face-walls of the Back Bays of the Gate-houses of the new Croton Reservoir, located north of 86th Street, in Central Park, were built of the best quality of hard-burned brick, laid in mortar composed of hydraulic cement of New York, and sand, mixed in the proportion of one measure of cement to two of sand. The space between the walls is 4 feet, and was filled with concrete. These face-walls were laid up with great care, and every precaution was taken to have the joints well filled and insure good work. They are 12 inches thick and 40 feet high, and the Bays, when full, generally have 36 feet of water in them.

When the Reservoir was first filled, and the water was let into the Gate-houses, it was found to filter through these walls to a considerable amount. As soon as this was discovered, the water was drawn out of the Bays, with the intention of attempting to remedy or prevent this infiltration. After carefully considering several modes of accomplishing the object desired, I came to the conclusion that the mode known in

England as "Sylvester's Process for Repelling Moisture from External Walls" was the easiest of application, and would be as effectual as any; and, on consulting Dr. Chilton, the chemist, I was confirmed in this opinion.

The results of the investigation were then submitted to A. W. Craven, Engineer of the Croton Water Works, for his decision, and his instructions were to adopt Sylvester's process.

This process consists in using two washes or solutions for covering the surface of brick walls; one composed of Castile soap and water, and one of alum and water. The proportions are: three-quarters of a pound of soap to one gallon of water, and half a pound of alum to four gallons of water, both substances to be perfectly dissolved in the water before being used.

The walls should be perfectly clean and dry, and the temperature of the air should not be below 50° Fahrenheit, when the compositions are applied.

The first or soap wash should be laid on, when at boiling heat, with a flat brush, taking care not to form a froth on the brick-work. This wash should remain 24 hours, so as to become dry and hard before the second or alum wash is applied, which should be applied in the same manner as the first. The temperature of this wash, when applied, may be 60° or 70°, and it should also remain 24 hours before a second coat of the soap-wash is applied, and these coats are to be repeated alternately until the walls are made impervious to water.

The alum and soap thus combined form an insoluble compound, filling the pores of the masonry and entirely preventing the water from penetrating the walls.

Before applying these compositions to the walls of the Bays, some experiments were made to test the absorption of water by bricks under pressure, after being covered with these washes, in order to determine how many coats the walls would require to render them impervious to water.

To do this, a strong wooden box was made, put together with screws, large enough to hold two bricks, and on the top was inserted an inch-pipe, 40 feet long.

In this box we placed two bricks, after being made perfectly dry, and then covered with a coat of each of the washes, as before directed, and

weighed. They were then subjected to the pressure of a column of water 40 feet high, and, after remaining a sufficient length of time, they were taken out and weighed again, to ascertain the amount of water they had absorbed.

The bricks were then dried, and again coated with the washes and weighed, and then subjected to pressure as before; and this operation was repeated until the bricks were found not to absorb any water. Four coatings rendered the bricks impenetrable under the pressure used.

The mean weight of the bricks (dry), before being coated, was $3\frac{7}{8}$ lbs.; the mean absorption was one-half pound of water.

An hydrometer was used in testing the solutions.

As this experiment was made in the fall and winter, after the temporary roofs were put on to the Gate-house, artificial heat had to be resorted to to dry the walls and keep the air at a proper temperature.

The following is a detailed statement of the cost of coating these walls:

| | | |
|---|---|---|
| Square feet of surface covered in North Gate-house | | 7,622 |
| " " " South " | | 11,208 |
| Total | | 18,830 |
| Superintendence of whole (96 days) at $2.50 | | $240 00 |
| Days' labor applying 4 coats soap, 120 | | |
| " " " alum, 120 | | |
| 240 at $1.50 | | 360 00 |
| 502½ lbs. soap | | 82 19 |
| Days' labor cleaning walls, 323½ at $1.50 | | 485 25 |
| 198 lbs. alum | | 7 67 |
| Coal for heating soap solution | | 8 00 |
| Labor tending fires, night and day, for drying walls, 185½, at $1.50 | | 278 25 |
| 27 tons of coal | | 216 00 |
| Wire brushes for cleaning walls | | 3 00 |
| 10 brushes for applying preparation | | 25 00 |
| Tubs and buckets | | 9 73 |
| Ladders | | 10 00 |
| Rope | | 38 42 |

| | |
|---|---|
| Stoves and pipes, and putting up same | $88 00 |
| Furnaces | 14 00 |
| Boiler for soap | 16 00 |
| Hydrometer | 2 75 |
| Scrapers, and sharpening scrapers | 1 93 |
| Platforms and staging (material and labor) | 6 00 |
| Brooms | 2 72 |
| Total cost of operations | $1,894 91 |

Costing, in all, 10.06 cents per square foot.

As soon as the last coat had become hard, the water was let into the Bays, and the walls were found to be perfectly impervious to water, and they still remain so.

## BRICK ARCH (FOOTWAY OF HIGH BRIDGE).

The brick arch of the footway of High Bridge is the arc of a circle 26 feet 6 inches radius, and is 12 inches thick; the width on top is 17 feet, and the length covered was 1,381 feet.

The arch, for 8 inches in thickness, rests on cast-iron skewbacks, which are prevented from separating by wrought-iron tie-rods.

The two first courses of brick of the arch are composed of the best hard-burned brick, laid edgewise in mortar composed of one part, by measure, of hydraulic cement of New York, and two parts of sand.

The top of these bricks, and the inside of the granite coping, against which the two top courses of brick rest, was, when they were perfectly dry, covered with a coat of asphalt one-half an inch thick, laid on when the asphalt was heated to a temperature of from 360° to 518° Fahrenheit.

On top of this was laid a course of brick, flatwise, dipped in asphalt, and laid when the asphalt was hot, and the joints were run full of hot asphalt.

On top of this a course of pressed brick was laid, flatwise, in hydraulic cement mortar, forming the paving and floor of the Bridge. This asphalt was the Trinidad variety, and was mixed with 10 per cent., by measure,

of coal-tar, and 25 per cent. of sand. A few experiments for testing the strength of this asphalt, when used to cement bricks together, were made, and two of them are given below.

Six bricks pressed together, flatwise, with asphalt joints, were, after laying six months, broken.

The distance between the supports was 12 inches; breaking weight, 900 lbs.; area of single joint, 28½ square inches. The asphalt adhered so strongly to the brick as to tear away the surface in many places.

Two bricks pressed together, end to end, cemented with asphalt, were, after laying six months, broken:

The distance between the supports was 10 inches; area of joint, 8½ square inches; breaking weight, 150 lbs.

The area of the Bridge covered with asphalted brick was 23,065 square feet. There was used 94,200 lbs. of asphalt; 33 barrels of coal-tar; 10 cubic yards of sand; 93,800 bricks.

The time occupied was 106 days of masons and 148 days of laborers. Two masons and two laborers will melt and spread, of the first coat, 1,650 square feet per day. The total cost of this coat was 5.25 cents per square foot, exclusive of duty on asphalt. There were three grooves, 2 inches wide by 4 inches deep, made entirely across the brick arch, and immediately under the first coat of asphalt, dividing the arch into four equal parts. These grooves were filled with elastic paint cement.

This arrangement was intended to guard against the evil effects of the contraction of the arch in winter, as it was expected to yield slightly at these points and at no other point, and then the elastic cement would prevent any leakage there.

The entire experiment has proved a very successful one, and the arch has remained perfectly tight.

The cost of labor and materials on this work was as follows:

Masons, $2.00 per day.

Laborers, $1.00 per day.

Asphalt, exclusive of duty, $\frac{47}{100}$ of a cent per lb.

Coal tar, $1.00 per barrel.

Sand, 50 cents per cubic yard.

*Note by General George S. Greene.*

In proposing the above plan for working the asphalt with the brick-work, the object was to avoid depending on a large, continued surface of asphalt, as is usual in covering arches, which very frequently cracks from the greater contraction of the asphalt than that of the masonry with which it is in contact, the extent of the asphalt on this work being only about one-quarter of an inch to each brick.

This is deemed to be an essential element in the success of the impervious covering.

XVII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

At a Meeting of the Society May 4, 1870.

Col. JULIUS W. ADAMS, Vice-President, in the chair.

## ON SKEW BRIDGES, AND ON THE CONSTRUCTION OF FALLS SKEW BRIDGE OVER THE SCHUYLKILL, NEAR PHILADELPHIA.

A PAPER read before the Society by J. DUTTON STEELE, Civil Engineer, Member of the Society.

Falls Bridge, over the River Schuylkill, on the Philadelphia and Reading Railroad, is a stone structure with six arches of eighty-three feet span and twenty-four feet raise. Each arch consists of eight square-built ribs of three by three feet in the section, and each rib sits eighteen inches back of its fellow, making a skew of twelve feet in a width of twenty-four.

Before entering upon a description of this structure and the mode of building it, it is due to the memory of one of the brightest ornaments of our profession (B. H. Latrobe, the elder), that I should refer briefly to the origin and history of ribbed arches, which, from the materials furnished me by B. H. Latrobe, the younger, I may be enabled to do with some little emphasis.

The sketch which I now submit to the Society is a design by Mr. Latrobe, in 1808, for a brick bridge over Rock Run, in Washington, D.C., with an arch of one hundred and fifty feet span and twenty-five feet

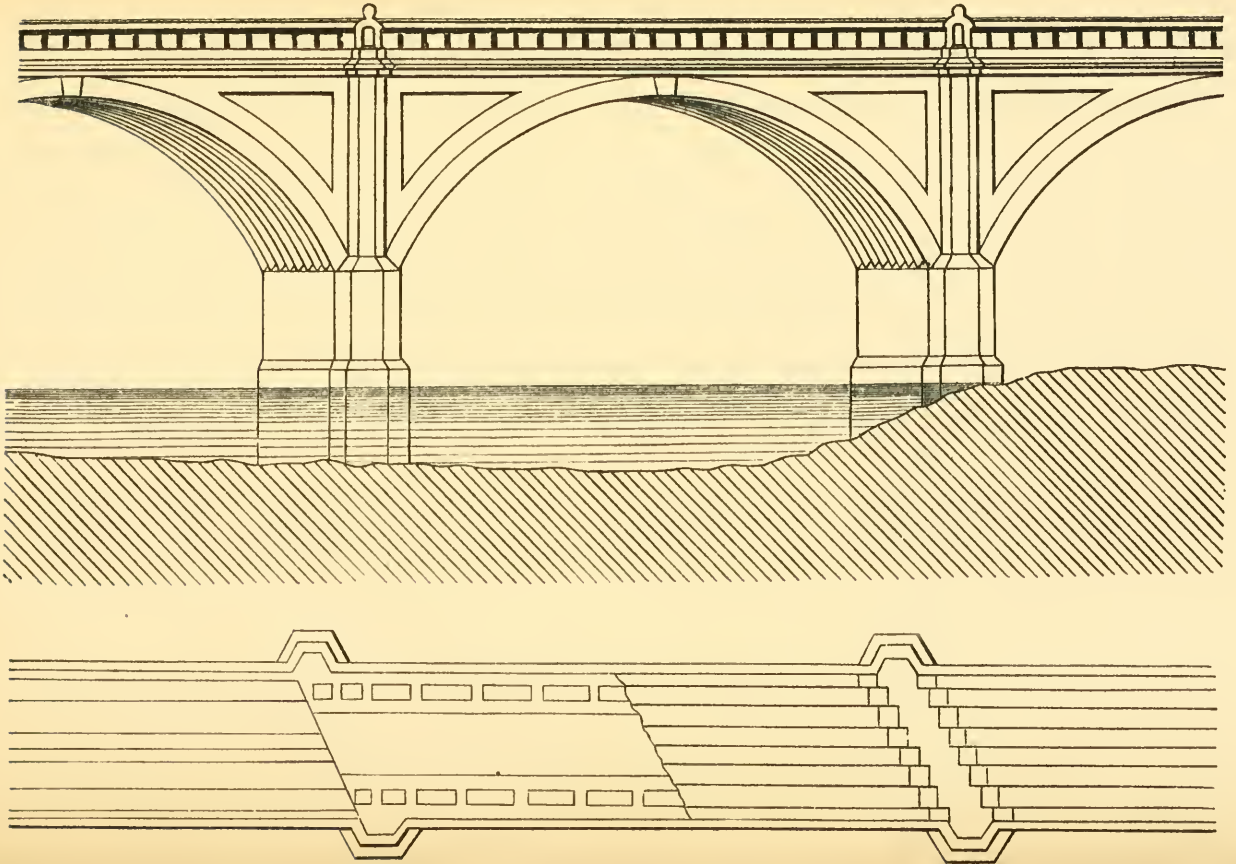
raise; it will be observed that the arch consists of four ribs of three and six feet in width, connected with transverse arches of eight and ten feet spans, and, from a note upon it, that it is a copy of a bridge previously built by the same engineer over the Medway, in England, and that he had applied for a patent. He also built a brick bridge over the canal in the District of Columbia, about the same time, which is yet standing as he left it more than fifty years ago; it is a ribbed arch of about sixty feet span, and is considerably skewed. I also submit a design of his for a bridge with ribbed brick arches over the River Schuylkill, at Philadelphia, with two spans of two hundred feet, and one of two hundred and fifty feet, which was made in 1802, but which was not executed.

We next find the system renewed in England for carrying wagon roads over the London and Croydon Railway; I quote from Weale's description of one of these structures printed in 1843:

"This an oblique bridge built on entirely novel principles, from the "design and under the direction of Joseph Gibbs, Esq., Engineer of the "Croydon Railway. The whole bridge is of brick work, and instead of "the arch being built in spiral courses as in the common skew bridge, "it is composed of four ribs or square arches three feet in width, and "the direction of the courses, in all these ribs, is at right angles to the "roadway over the bridge. It is evident that a bridge may be built on "this principle at any angle, however acute, and all the expense and "trouble of skew arches avoided. The bridges of this kind on the "Croydon Railway are universally admired for their elegance and "simplicity." But Mr. Gibbs had been antedated more than a quarter of a century by Mr. Latrobe both in England and America; and it is not more remarkable that this simple mode of building oblique arches should have been so long hidden from the architectural world than that extinct races of men, who have left behind them monuments of masonry which are studied to advantage in the present enlightened age, were without the knowledge of the arch in any of its shapes.

The first ribbed arch bridge for sustaining the weight and jar of railway trains in this country, was built on the line of the Philadelphia and Reading Railroad in 1848, at a point known as "Third Crossing." It is a stone structure, with three spans of forty-two feet and a raise of twelve feet. Each arch consists of four square built ribs, with a backset of one and a quarter feet and a skew of five feet.

# FALLS BRIDGE.



Circumstances made it necessary to remove the centres from this structure as soon as the arches were keyed, and for an entire winter they sustained the heavy traffic of that road unaided by backing or spandrels, and thus their sufficient stability was demonstrated in the most practical manner.

This bridge was duplicated by Mr. Edward Miller on the Pennsylvania Railroad about a year later, after which the system came into general use.

The designs for Falls Bridge were made in 1852, and the work was commenced in 1853, and finished in 1856; it was the most elaborate application of ribbed arches of its date. The feature in its construction which has attracted most attention is the fact of its occupying exactly the same site as did the wooden structure for which it is the substitute Steamboats plied under it whilst it was building, and passengers were surprised to see the old wooden structure gradually disappearing and the new stone bridge taking its place, but the most difficult part of the work was the foundations.

The Falls of Schuylkill, which gave name to this locality, was originally a considerable rapids in the river where the waters found their hurried way among granite boulders at the head of tide. These boulders had been connected with deposits of riprap forming wing dams to drive machinery, and at a later date both the boulders and ripraps had been submerged to a depth of five or six feet, by the construction of Fairmount dam of the Philadelphia Water Works, and stern-wheeled steamboats plied over them. Thus it was that the rock bed of the river had become covered with masses of loose stones to a depth of five or six feet, with about an equal depth of water over them.

As coffer dams could not be founded upon these loose materials their sites were cleared with diving bells before they were sunk, that the filling might rest upon the rock.

The foundations were obtained in from twelve to fifteen feet of water, and in all cases the cut stone masonry not only rested upon, but was fitted to, the rock bed of the river.

The diving bells were made of plate iron suitably weighted and supplied with air through a hose attached to the top. The workmen remained in them five hours at a time, and the air was changed every fifteen or twenty minutes.

Two of the piers occupy the same places as did the piers of the old structure in which cases strong trestles were placed inside of the coffer-dam to sustain the wooden superstructure whilst the old piers were being removed and the new substituted for them.

Two seasons were occupied in obtaining the foundations and raising the piers to the springing line, and one in turning the arches and building the spandrels.

In describing the mode of turning the arches without interrupting the traffic upon the railroad above, or on the river below, it must be observed that the structure which they took the place of was a deck lattice bridge, the bottom chord of which was five feet above the springing line of the stone arches. After the new piers were built, the first operation was to support this lattice superstructure upon strong trestles resting upon the centres, and between the skew-backs. These trestles were not removed, and they are the only wood-work built into the masonry. It will be observed thus far, that we have increased the strength of the old structure by reducing its spans, and the remaining piers of the old bridge were then taken down.

The centres for turning the arches were of lattice, corresponding in plan with the trusses of the old bridge, and the trusses were made use of as a portion of the centring by bolting segments upon them. Working platforms upon which were rail tracks for moving the stone, and derricks for handling them, passed along either side of the bridge, supported upon beams which rested on the chord of the old structure about ten feet above the springing line.

These arrangements being completed and the arch stones being ready, the work of turning the arches was a simple operation, and did not consume a great deal of time. That portion of the old lattice trusses above the arches was cut away as the work progressed, and the rail tracks on the top were supported upon the masonry. When the arches were keyed those portions of the old structure below them were lowered away with the centring.

The tops of the arches were covered with flat stones from four to six feet long, which gave some bond to the ribs, enough for ordinary cases; but the constant passage of coal trains caused more vibration than was desirable, and tie rods were placed across the arches, binding the key-

stones on either side together, for the purpose of steadying the ribs while the spandrels were being built.

Four thousand stone, each three feet square, and averaging about one foot thick, were required to turn the arches, and this gave occasion to note an unexpected difficulty in obtaining so large a number of sound stones of one definite size; no bond of masonry is deemed admissible between the ribs of oblique arches.

I also submit to the Society several other plans of stone bridges on the Philadelphia and Reading Railroad, which will indicate the general character of the structures; if they may be deemed of little value, they will do no harm.

The cylindrical spandrel arches have produced satisfactory results, lightening the structure over the piers, and giving bond to the spandrels.

All these bridges were built in the place of wooden structures without interrupting the business of the road, and the practice gave an unusual opportunity of observing the extent to which the stability of simple stone arches without the support of spandrels or backing may be depended upon. The centres were generally removed as soon as the arches were keyed, and the backing carried up to those joints of the arches which made angles of thirty degrees with the horizon, and in no case did the arches so supported fail to sustain the heavy trains which were passing over them, without material vibration,

The plan of "Peacock's Locks Bridge" was a ribbed arch of seventy-six feet span and twenty-three feet raise over a canal. It was necessary to turn this arch in a severe winter, with the temperature considerably below freezing point, from the time the first stone was laid until the centres were removed, and it was interesting to observe the settling of the ribs as the frost left the mortar. They separated, at one point as much as three inches, but retained their stability perfectly, and after the cracks were filled and the spandrels built, no farther derangement took place, and it would take a close observer, at this day, to discover any of the injurious results of that hard, and, as many thought, precarious winter work.

XVIII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

## ON BLASTING.

### MEMORANDA OF TWO BLASTS FIRED APRIL, 1869, ON THE UNION PACIFIC RAILROAD.

A Paper presented by E. P. North, Civil Engineer, Member of the Society.

The cut was through dark blue limestone which had been partially taken out so that there was left in it a mass about 100 feet long and 18 feet deep, with the ends well squared up. The average width thrown out being 24½ feet, the total amount was 1,633 cubic yards.

The original depth of the cut was 31 feet, of which 13 feet had been removed.

The powder was put in two wells, 34 and 20 feet respectively from the two faces, leaving about 46 feet between the two blasts.

The first well was sunk vertically to grade (18 feet), two chambers were then excavated along the axis of the cut each 6 feet in length. The second well, also 18 feet in depth, had a slant of about 10° towards the first well, with a chamber in the same direction about 4 feet long.

The wells, which were as small as it was possible for a man to work in were blasted with nitro-glycerine. The first with two chambers required 9 eight hour shifts of two men each, and 15 lbs. of nitro-glycerine.

*Cost of 1st Well.*

| | |
|---|---|
| Labor 18 days at $3 | $54 00 |
| Nitro-glycerine, 15 lbs. at $2 | 30 00 |
| | $84 00 |

The second well with one chamber required 6½ eight hour shifts of two men each, and 11 lbs. of nitro-glycerine.

*Cost of 2d Well.*

| | |
|---|---|
| Labor 13 days at $3 | $39 00 |
| Nitro-glycerine, 11 lbs. at $2 | 22 00 |
| | $61 00 |

The first well was loaded with 78 and the second with 33 kegs of powder, 111 kegs in all, which at 25 lbs. per keg is 2,775 lbs., or about $1\frac{7}{9}$ lbs. per cubic yard. This large amount of powder was used on account of the rock being at the bottom of the cut, and firmly bound by its sides. Also from the nearness of the track, which made it desirable to throw as much material out of the cut as possible, to save time.

The powder was first covered with logs firmly wedged into the wells and then tamped with fragments of stone well rammed in layers. Three fuses were used for each charge, cut carefully of the same length. The blasts were successful, exploding within a few seconds of each other. Only about 600 cubic yards of material were left in the cut, which were removed by 6 eight hour shifts of 18 men each.

*Cost of blasting and removing* 1,633 *cubic yards of rock.*

| | |
|---|---|
| 1st well | $84 00 |
| 2d " | 61 00 |
| 111 kegs of powder at $10 | 1,110 00 |
| 120 feet of fuze at 3 cents | 3 60 |
| Logs, loading, etc., about | 25 00 |
| Loading material left in cut into carts, 18 men 6 days at $3 | 324 00 |
| | $1,607 60 |

Or less than $1 per cubic yard. To which is to be added for superintendence, carting, etc., about 10 per cent., making a total of $1.10 per cubic yard.

## SUBMARINE BLASTING.

A Paper presented February 28, 1870, by F. Collingwood, Civil Engineer, Member of the Society.

In excavating for the foundation of the Brooklyn pier of the East River Bridge, the bottom was found to have, running about through the centre of the excavation, a ridge of exceedingly hard material, being composed of boulders of all sizes imbedded in compact clay.

As the dredges would scarcely scratch the bottom after this was reached, the following method of loosening it was adopted:

A solid iron pile, 18 feet long and 5 inches diameter, shod with steel, with a ring at the upper end for hoisting, was driven by an ordinary pile-driver down to the desired depth. On withdrawing it, it was found that a perfect hole was left, into which a tin canister containing 13 pounds of powder was easily inserted. The effect of the charge was to leave a crater reaching at the centre below the desired bottom. The success of the experiments was so decided that another pile of 5 inches diameter and 22 feet long, and one 6 inches in diameter and 22 feet long, were procured. By the aid of these, with two pile-drivers, and crews, and a diver and assistants, from 20 to 40 blasts per day were fired at a depth of 18 feet below mean high tide.

The dredge was able (after the bottom had been gone over in this way) to excavate from 50 to 120 yards per day.

The material was from 2 feet to 8 feet deep.

Time of driving about 5 minutes.

Cost probably about $3 to $4 per cubic yard.

When the pile fastened between two boulders it had to be loosened by blasting round it.

The economy of the operation as compared with the usual method of drilling is very decided.

XIX.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852

# TRANSCATIONS.

## SECOND ANNUAL CONVENTION.

### FIRST DAY'S PROCEEDINGS.

Rooms of the Chamber of Commerce, New York, June 15, 1870.

The President, A. W. Craven, in the Chair.

The President called the meeting to order at 2 P. M., and the roll being called by the Secretary, the following members answered to their names, viz.: Messrs. Adams, Allen, Auchincloss, Brown, Bacon, Boller, Barnard, Brevoort, Copeland, Craven, Constable, Church, Coryell, Croes, Clark, Culyer, Colman, Collingwood, Davidson, Evans, Ford, Gilliss, Gould, Hatfield, Haswell, Lowthorpe, Macdonald, Morse, Morris, McAlpine (W. J.,, Norman, Owen, Rowland, Swift, Stanley, Steele, Slataper, Thompson, Walling, Ward (J. F.), Ward (C. H.), Worthen, Von Wesseley, Wilson, Van Buren, and Whipple; total, 46.

The President delivered the following address upon the condition and prospects of the Society:

Fellow Members,—It is not my intention to trespass upon your time with a long address. In the substance of the various professional papers with which I hear we shall be favored to-day, there will undoubtedly be

much more to interest you than in an address of this kind; and in their extent these papers will be quite sufficient to occupy the few hours of this day's session.

It seems to me, however, that in this, our Annual Convention, it is proper to advert in a brief way to the past history of our Society, its present condition, and its future prospects; and that we *can* advert to them with pleasure, will, I hope be, in some degree, a compensation for the tedium generally attendant upon a recital of mere statistics. To bring before you clearly our *present* condition, as compared with the *past*, I shall be obliged to repeat some facts which have been embodied in former addresses from this chair. For this I ask your indulgence. Statistics do not claim to be original conceptions, and their repetition is therefore not plagiarism.

Our Society, as you all know, was first formally organized in the year 1852. At that time there were scarcely enough members within the immediate vicinity of New York to supply incumbents for the offices alone. Still we met, and strove our best to nurse the infant in whose health and growth we all had so deep an interest. We met, as our early records show, to the number of seven—five, sometimes three, on an evening, and *every man present was an official.* We could not afford to hire a room, and so our "corporal's guard," or rather our guard of corporals, met at night in one of the vacated rooms of the Croton Aqueduct Department in this city. There we may be said to have worked hard—for even if we did nothing else, to courageously and persistently attend *such* meetings was to work hard. The struggle lasted three years, until at last, in March, 1855, we were obliged to succumb. Our failure seemed to be so complete, that with some of us there was no hope of recuperation, and had there been any means of returning to absent members their respective portions of the money remaining in our hands, the majority of the active members would have counselled such return. Some, however, still retained their courage, and urged the careful investment of our funds and the safe storage of our few books and papers until hoped-for brighter days. The result has proved the value of that courage and the wisdom of that advice.

Our syncope lasted twelve years; and when, resolved upon one more strong effort for life, we came together in October, 1867, we started with a fund which added materially to our strength and spirits. We took our present rooms, and, so far as our limited means permitted, we tried to make them attractive. We were no longer vagrants. We had at last established an

actual habitation of our own; a point to which each member might come as to his own house, and at which he might meet those who, with him, were interested in a common enterprise; and so we all felt renewed hope. That hope has, in my opinion, been justified by events; for, although we are still far behind what we all desire to be, and though some impatient hearts are still unsatisfied, we have, considering the character of our work, and the age of our organization, made what may fairly be called large strides. Look at the facts! At the time of re-gathering for this work, the members on our old register, known to be alive and thought to be willing to aid in the attempt to revive the Society, numbered in all only twenty-eight. Of those who were present in the city to speak positively to that point, there were but thirteen. This was in October, 1867, not yet three years ago. Now we count upon our rolls 179 regular members, and the number is constantly increasing. During the past year the "Fellowship Fund," with the object of which you are all familiar, has been established, and has received the names of fifty subscribers. When fully paid in, the interest on this fund will aid materially in our annual necessary expenditure for publication. We have of bound books and pamphlets, which have been presented to the Society, about 350 volumes; besides a number of maps, charts, and drawings, etc.; and, like our members, these too are constantly increasing in number. Since the commencement of the present year of the Society in November last, we have had meetings on the 1st and 3d Wednesdays of every month. In no one case has it yet been necessary to adjourn for want of a quorum, and at many of them the number of members present ranged from twenty to thirty. There have been read at these meetings numerous original papers, many of which embodied information not easily obtainable in any other way, but most valuable in itself, and showing ability, study, and close, intelligent observation on the part of the writers. This, in a city like ours, shows an interest increasing, and most cheering; for it must be remembered that we have not the same advantages for collecting together a number of engineers as are enjoyed by the cognate institution in London. For all public operations in Great Britain, London is the one centre, and the proportion of her engineers constantly within easy access of Great George street, is far greater than we, who are accustomed to being thinly spread, scattered broadly over an almost boundless continent, can very well realize. When we compare, too, our inception, progress, and present condition with those of the English In-

stitution of Civil Engineers, humble as we yet are, we find still more light on our horizon. Those who, with Smeaton, commenced the first association of this kind in Great Britain did so one hundred years (99) ago. After a long period of varying health, and sometimes of exanimation, the present Institution sprung up from out of that first gathering about Smeaton; and even this latter has been in existence fifty-two years. Our first gathering was but seventeen years ago, our sleep was twelve years in duration, and our life since our resuscitation has not yet completed its third year! I do not, of course, mean to claim equality with that eminent and well-established organization, the English Institution of Civil Engineers, but I think it not too much to say, that so far as any one, aided by a fair comparison with living examples, can predict the status of the future man from the physical and intellectual condition of the boy, we have good analogical reasons for present courage and confident hope in ultimate brilliant success.

Another indication of progress, and with it prosperity, may be found in the capacity or rather the want of capacity in our rooms. It is a case of unequal expansion. Our members have so much increased in number, that frequently in our regular meetings our now small apartments do not furnish sufficient space for those attending. The same is true as to our growing library. Kindred associations by exchanges, and public institutions and individual members by direct presentation, have been so courteous and generous in adding to our store of books, pamphlets, etc., that now we have actually no room to place what we possess in accessible position; and when we come to receive further donations, such as you will see by an announcement I shall make in another part of this address we have reason to expect, it will be impossible, for any practicable purpose, to remove the books from the boxes in which they may be sent.

You will readily perceive that this phase of our progress superinduces the necessity of obtaining larger apartments. For this reason, as well as to make up the sum necessary for publishing, more funds than we can yet command are required. It is therefore proposed to increase the amount of the entrance fee, and of the annual assessments; and it is believed that such increase will be cheerfully concurred in by every member of our Society. Throwing out of the question any other reason for this increase, it is safe to assert that, with sufficient funds for their prompt publication and distribution, the papers read at our meetings will be worth more each

year than the amount now paid or to be paid for annual subscription. From no other source could be obtained at so moderate a cost, the practical information really valuable in our profession, which might be embodied in the written personal experience of intelligent and observant engineers spread far and wide over our vast country; meeting, combating, and overcoming exigencies, which must exceed in variety and novelty those arising in any other one country in which the foot of the engineer is making progress.

Coming back to the increasing brightness of our prospects, and to the increasing interest on the part of members which is the sole cause of that brightness, it seems an appropriate time for reference to one of the most marked proofs of real interest in our Society which has been given from any quarter since its original organization. I refer to the recent proffer to us by our late President, Wm. J. McAlpine, of a large portion of his professional library. Selected by a man of fine ability, excellent education, and large practical experience, this donation must, beyond all doubt, contain works of reference very valuable to our Society. The manner and terms of this offering are set forth in a letter of Mr. McAlpine which was received at our last regular meeting, and which will be read to-day before the Convention in its proper order; but it seems to me that, without in any degree intending to anticipate, as evoked by this address, any portion of the pleasure solely referable to the contents of that letter, it is only fitting that from this chair should come a prompt acknowledgment of the value of this gift, and a direct appeal to the Society to receive this as a proof that, among its members, there exists real life, real interest, and real determination to make our long struggling association a final success.

In truth, we may assume that the quicksands in and about our foundation have been confined, and that abundant material of excellent quality is close at hand wherewith to build our superstructure; and notwithstanding the modest doubts of some of our members, I think myself justified in saying that, with the exception of the Franklin Institute, there is to-day no kindred institution in our country, which so far as permanent vitality is concerned stands on a firmer base than the American Society of Civil Engineers.

Let me not be understood to infer that we are now beyond the necessity for exertion; on the contrary, now is the very time for effort, because there is now a promise that it will be repaid. I have mentioned the pre-

ceding facts only to encourage you to exertion, by exhibition of proof that your zeal, if given, will not be thrown away. But it is needed. The dangers of the foundation are overcome, and the first courses are secured in place; but many a goodly superstructure has been arrested near its commencement, and stood for years thereafter a monument of the lack of ability, and of practical resource, in its projectors. It is for you now to show that there is no lack of ability or of zeal in this Instititution. She needs your aid. To secure even moderate advancement in the prosecution of our work, your assistance is required, and from every member of the Society it is most earnestly asked. There is scarcely a member, old or young, who cannot, from his own experience, send in some contribution in the shape of a paper. Be it long or short, it will be welcome, as showing zeal and interest; and in the vast variety of experiences throughout our country, it can scarcely fail to contain some points of information novel and valuable to all of us. Original papers form the main, if not the only, reliable food for the permanent health of our Society. They are the substance; the discussions which follow are the gastric juice which helps that substance to assimilate with the system and nourish the body. The most of this food heretofore has been furnished by the resident members. We ask the non-residents, near and far, to send in their proportion of the needed supplies. If you cannot bring it yourselves, and thus give us a double pleasure, send it either through some friend or directly to the Secretary. It will be thankfully received and fully appreciated, and by the aid of the printer your contribution will be made a source of interest and improvement to your fellow-members in every portion of our country.

In this connection permit me to call to your memory, and urge upon your consideration, the question of the Fellowship Fund. Upon this we materially depend for ability to continue the regular publication of our papers. From the ease with which a very few of our members have obtained the names of the fifty-two present subscribers, it seems very certain that the interest and the will to do this service to our Society is all that prevents us from making this number three times fifty. I believe there is scarcely a member among us who cannot obtain at least one subscriber. I do not say that each member can number among his friends several persons able and willing to subscribe, but that in the particular community surrounding each one of us individually, there is at least one

person of means, who, after a proper explanation of this subject, will cheerfully become a Fellow of our Society.

Of the comparatively few—not more than one dozen in all—by whose zeal the present number of Fellows were brought into our Association, some have obtained three or four names. One member, Mr. Rob. H. Brown, obtained the names of eight subscribers alone, and this within two weeks after receiving notice of the object of the Fund. All of these names have been cheerfully and in many cases most gladly given. The request for such a subscription is not a solicitation for alms, or for contributions. The object of the Fund is an acknowledged public benefit. To each man of property in the country the advancement of engineering science is a matter of personal pecuniary interest; for the value of his investments, whether in established works or in the prosecution of new enterprises, rises or falls with the intellectual and moral worth of the engineer who plans and carries out the constructive operations.

Allow me, then, to ask your active aid in this matter. If you once set about it you will find it an easier task than you now imagine, and it needs but that each member should undertake his portion of the task, to speedily secure an amount which will at once put our Publication Fund upon a secure and most efficient basis.

In concluding this short address, I beg to add my thorough conviction that, with an intelligent appreciation of its value to all of us, and renewed efforts on the part of its members, each one who can do so contributing some item from the stores of his energy, his intellect, or his experience, our Society will soon become what we all have so long wished it to be, and that its well-recognized and permanent effect will be, as foreshadowed in the 2d article of our constitution: "The professional improvement of "its members; the encouragement of social intercourse among men of "practical science: the advancement of engineering in its several "branches, and the perfect establishment of a central point of reference "and union for its members."

Communications being now in order, the Secretary read the following letter from Mr. W. J. McAlpine, which had been referred to the Convention from the last regular meeting:

Office of the Architects and Engineers,
45 N. Pearl st., Albany, N. Y.,
*May* 31, 1870.

To Jas. O. Morse, Esq.,
*Treasr. Amr. Soc. Civ. Engs*

Dear Sir.—Referring to a recent conversation with you, I have now to request that you will lay before our Society the following proposal:

That a committee of yourself, Mr. Tracey, and Mr. ———, be appointed to confer with me and arrange for the present custody and ultimate ownership of a large portion of my library of books, and bound volumes of manuscripts and drawings.

For reasons hereafter stated, I propose to place these volumes in a Trust, and, if the Society will provide cases and keep them insured, to place them under the control of its officers for ten years, at the expiration of which time, if our Society continues upon a stable basis, the trustees are to convey the title of the volumes to the Society. Yourself, and some of the other members of our Society, know the value of these volumes, one of which is their completeness in regard to the early history of the profession in this country, and my desire is to keep them together where they will be of the greatest service to Engineers.

The experience of our Society, like that of others, does not guarantee its certain future maintenance, and hence I propose to place these volumes in a Trust until another decade shall determine its permanency.

I suggest the selection of three ex-officio trustees, and two individuals to be named by me. For the former, may be the President of the Society, the Engineer of Public Works of New York city, and one other official to be suggested; and for the latter, my brother and one other friend.

If the Society accepts this offer, I would suggest that the volumes be catalogued and valued by its officers, and that the members who take them out of the Library shall be responsible to the extent of such valuation. These and any other arrangements can be adjusted between the committee and myself. I offer these volumes to our Society as a mark of my earnest wishes for its success, and of my high regard for its members,

with the hope that it will form a nucleus for such a Library as our Society ought to possess.

Very truly yours,

WM. J. MCALPINE.

On motion of Col. Adams, a vote of thanks to Mr. McAlpine was adopted.

On motion of Mr. Rowland, the following resolution was also passed:

"*Resolved*, That this Society accept the kind donation of Mr. McAlpine, subject to such conditions and restrictions as may be agreed upon between himself and the Society."

The following papers were then read:

1. The Wave Motion in Fresh Water—W. J. McAlpine.
2. The Engineer in Courts of Law—W. J. McAlpine.
3. Cast and Wrought Iron in Bridge Construction—F. C. Lowthorp.
4. Truss Bridges—S. Whipple.
5. Permanent Pier Construction in Masonry—Gen. Barnard.
6. Compressed Air as a Motor—J. Dutton Steele.
7. Experiments on the Flow of Sand and Water—F. Collingwood.

After the reading of the above papers, the Society adjourned, to meet again at 11 o'clock the following day on board the steamboat chartered for an excursion around the harbor.

NOTE.—The publication of the papers on Wave Motion, by Mr. McAlpine, and on Permanent Pier Construction, by Gen. Barnard, are necessarily delayed.

## SECOND DAY'S PROCEEDINGS.

*June 16th.*

In pursuance of the adjournment, the Society met at 11 A. M., and employed the day in visiting such points of engineering interest in the harbor as time allowed. In addition to the regular members, there were present as invited guests Gens. Cullum, Tower, Wright, Warren, Gilmore, Newton, and Capt. Raymond, all of the Engineer Corps, U. S. A.; Forts Tompkins, Hamilton, and Wadsworth were visited, and much time was spent inspect-

ing the operations in progress under General Newton for the removal of the obstructions at Hell Gate.

Returning to the city at six o'clock, the Society and its guests reassembled at the Astor House to partake of the annual dinner, which was characterized by good fellowship, kind feeling, and professional sympathy throughout.

ALFRED P. BOLLER,
*Secretary.*

XIX.

2

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

*Extracts from a Paper read by* WM. J. MCALPINE, *Civil Engineer, Member of the Society.*

## ENGINEERS IN COURTS OF LAW.

The Court always understands that an engineer when called upon the stand as a witness, has been previously advised in regard to the professional questions upon which his direct examination will be made, and that he has prepared himself by study and reasoning to apply to the case in hand all of the scientific principles which are necessary to elucidate it.

If he is a true man (to his profession) he will always give the results of his study, whether it bears for or against the side upon which he may happen to be called.

His mission, and his profession, is simply the elucidation of truth.

No provocation on the part of the lawyer will justify the witness in giving an uncourteous reply, and he is very unwise when he thinks that he can give back a sharp or witty answer.

If the lawyer really uses improper language in addressing the witness, the latter can appeal to the Judge.

It most frequently happens that the opposing counsel puts questions to a professional witness, which would require from him hours or days of deep study before he can answer them perfectly. In such cases he may

reply. "I have not considered the subject under that aspect sufficiently to reply; or, he may say, "I require a little consideration before I can reply: I will make a note of your question and answer it as soon as possible."

The witness is often called upon to express an opinion on some subject, which is a matter of exact or approximate measurement and calculation: it is often impossible for him to make such calculations accurately in the presence of a room full of people.

His proper course, under these circumstances, is to take a note of the question and inform the counsel that he will make the calculation and give it in writing. In strict law, however, a witness on the stand is not compelled to make any calculations, except those of a simple and elementary character. It is as absurd to call upon the engineer to perform duties of a professional character, when upon the stand as a witness, or to give professional opinions, as it would be for a lawyer, under the same circumstances, to be called upon for legal opinions upon some grave question of law.

It is unwise to attempt to conceal from the Court that the engineer has been in consultation with the lawyers upon the side on which he has been called, or that he has been or is to be paid for his services at the usual professional rates.

It is perfectly proper for an engineering witness to obtain from the counsel all of the points of the case beforehand, so that he may carefully examine "the books" and duly consider the points in his own mind, so as to be prepared to give the Court the results of his professional knowledge, experience and study. In regard to all the facts of the case, however, he stands in the same light as an ordinary witness.

In England, for many years, the engineer has been called into a new field of duty, viz., that of acting as an associate or adviser to the counsel employed, that is in regard to all of the professional (engineering) points of the case.

This position abroad has long since become one of the highest distinction, and has been rewarded with the highest compensation, and no lawyer would now venture upon the conduct of a case, involving engineering questions, without the aid of such professional assistance.

Of late years I have frequently been called upon to undertake the investigation of cases in courts of law, where important engineering questions

were involved, and I have invariably insisted upon the right to determine the line of the professional argument of the case and also to select the witnesses to maintain it.

I admit, however, that it is only more recently that I have taken the high ground of the English engineers, but having done so with effect, I am satisfied that it may be more frequently done, and, if others in the profession will do likewise, it will not be long before we shall open to our profession in this country a new and remunerative field of labor, in which the engineer will win new laurels and give new importance and dignity to his profession.

XIX.

3

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

*Extracts from a Paper read by* F. C. LOWTHORP, *Civil Engineer, Member of the Society.*

## ON THE USE OF CAST IRON FOR COMPRESSIVE MEMBERS OF IRON BRIDGES.

There have been many bridges built entirely of cast iron, which, so far as I can learn, have answered their purpose admirably. More than eighty years ago a cast iron arch bridge of 240 feet span was built at Wearmouth, England, and upwards of fifty years since another of three spans of 240 feet each, across the Thames at Southwark. Many others have since been erected in the British dominions and on the continent.

On this side of the Atlantic we have at least two notable specimens: one of two spans of 200 feet each, across the Schuylkill at Philadelphia, a much admired bridge, designed by Strickland Kneass, Esq. The other a bold and remarkable, and, judging from a photograph I have seen, a handsome structure, built over Rock Creek, at Washington, D. C. This bridge has a clear span of 200 feet, a rise of 20 feet, and a width of 26 feet 4 inches, and has two supporting arches, which are formed of cast-iron pipes four feet in diameter, through which is brought the entire water supply of the city. It was designed by Major-General Meigs, of the U. S. A.

Hodgkinson, in his experiments on columns or hollow cylinders, the bearings of which were flat or at right angles with their axes, found that those of 48 diameters in length (10 feet long by 2¼ inches diameter) required a force of 18,000 lbs. per square inch to break them, and that others of 34 diameters in length (10 feet long by 3½ inches in diameter, required 26,000 lbs. per square inch to break them. His experiments also demonstrated the facts that columns of the same dimensions, having both ends rounded, would require but one-third, and with one end rounded and one flat end, two-thirds of the above forces to break them. In many of the hollow columns tested, at the point of fracture the metal was found to be much thicker on the one side than on the other, but they appeared to be generally as strong as those whose sides were of uniform thickness. (See Francis' work on cast-iron columns.) Mr. Whipple, in his valuable treatise on bridges, page 52, observes: "With regard to the simple positive and negative strength of iron, it is only necessary for me to state, in this place, that, as the result of a multitude of experiments, a bar of good wrought iron, an inch square, will sustain a positive strain of about 60,000 lbs., on the average; and a negative strain in pieces of a length not exceeding twice the least diameter, of about 90,000 lbs. Cast iron resists a positive strain equal to from 15,000 to 30,000 lbs. to the square inch, but usually not over 18,000 lbs.: in fact, it is seldom relied upon to sustain this kind of strain, and its power of resistance in this way is not so well determined as in the case of wrought iron. But cast iron resists a negative strain even better than wrought iron—its power of resistance being from 80,000 to 140,000 lbs., seldom less than 100,000 lbs. to the square inch, for pieces of a length not exceeding twice its least diameter. But in pieces of such dimensions as must usually be employed in bridges, fractures would take place by lateral deflection, with a much smaller force than would crush the material.

"It is therefore necessary to take into account the length and diameter as well as the area of cross-section, in order to determine the amount of negative strain which a piece of cast iron, or any other material, may be relied upon to sustain."

According to the numerous experiments of Major Wade, of the United States Ordnance Corps (see Haswell's Engineers' and Mechanics' Pocket Book, page 484), we have the following as the comparative tensile, compressive and torsional strength and hardness of wrought and cast iron:

CAST IRON.

| | Tensile. | Compressive. | Torsional. | Hardness. |
|---|---|---|---|---|
| Least..... | 9,000 | 84,529 | 1,660 | 4.57 |
| Greatest .... | 45,900 | 174,120 | 3,060 | 3.351 |
| Mean..... | 31,829 | 144,906 | 2,760 | 22.14 |

WROUGHT IRON.

| | | | | |
|---|---|---|---|---|
| Least..... | 38,027 | 40,000 | 1,296 | 12.14 |
| Greatest .... | 74,592 | 127,720 | 1,836 | 14.45 |

Having had some experience in the construction of iron bridges, I will state some of the facts which have fallen under my own observation. During the years 1856–57, I constructed for the C. & F. R. R. Co., of Pa., across the Jordan Creek and Valley, a single track Deck iron bridge, about 1,120 feet long, and 89 feet high; the bridge consisted of eleven spans, of 100 feet each; the side trusses (see Figures 1, 2, 3), were double cancel, and were divided into 12 panels each; they were 16 feet high, and were placed 10 feet apart from centre to centre. Each lower chord (see Fig. 4, C. C. C.) was formed of eight round bolts of wrought iron, which were connected longitudinally with screw swivels (B. B.), and laterally with combination or angle plates of cast iron (D. D.), through which the chord bolts (C. C. C.) pass—the plates being held in position by means of the jam nuts (*n n*).

The end panels had each but one chord-rod (Fig. 1, C. C.), which was secured to the base plates of the end posts, in such a manner as to admit of the free expansion and contraction of the metal in the bridge. All of the post bearings were pivot at bottom, and knuckle-joint or hinge at top; the posts were of cruciform section, the webs of the end posts were 12 inches wide by $\frac{5}{8}$ of an inch thick at the middle, and tapered to about $5''\text{x}\frac{3}{4}''$ at each end (see Fig. 11); the webs of the intermediate posts varied from $9''\text{x}\frac{1}{2}''$ to $9''\text{x}\frac{5}{8}''$ thick at the centre, and tapered to $4''\text{x}\frac{1}{2}''$ and $4''\text{x}\frac{5}{8}''$ near the ends (see Figs. 4 and 10); enlargements, recesses, &c., were made in the posts for the passage of the main rod, counter diagonals, etc. (See Figs. 1, 2, 3, 4, 10, 11.)

The upper chords (see Figs. 4, G. G. G. and F.) consisted of hollow cylinders, strengthened with 4 longitudinal webs, and were turned off to a square bearing to receive the tenon of the cap F. The plate H, to which the floor beams (*z z*) are secured, is made to clamp, loosely, the upper part of the cap F, so as to admit of a free expansion and contraction of

the frame of the bridge, the wood-work of the track remaining unaffected.

Cross struts and vertical cross ties were secured at every panel of the bridge, as shown in the end and intermediate sections (see Figs. 2 and 3, *v. v.* and *s. s*). The upper part of the bridge was laterally braced throughout; but there was none in the bottom, except the end panels of each span.

The bridge was supported on trussed piers of cast and wrought iron, which varied from about 30 feet to 54 feet in height; these stood upon and were anchored fast to foundations of massive masonry, which were raised a few feet above high-water mark.

The extreme end posts of the bridge rested on abutments of masonry, the back walls of which were carried up to grade. Figs. 1, 2, 3, show a general outline of the bridge and piers; and, in the latter, the columns P. P. P. were of cast iron, of cruciform section, excepting the ends, which were cylindrical, and were turned off to fit into each other with tenon and socket joints, at the junction of each section of the piers. At bottom each column rested upon a pivot base, which was bolted to the coping of the masonry.

The cross struts, which were of round, wrought iron, 2¼ inches diameter, passed through the columns; they had two screw nuts at each end (for struts, see s. s. s.) for the purpose of retaining in position the columns and the eyes of the diagonal tie rods, t. t. t.

On the top of each set of columns (four constituting a set) was placed a cast iron frame, which for convenience, I call a spider frame. The spider frames were adjusted and held in position by means of four 2¼ inch vertical screw bolts, each about 15 inches long, the bottoms of which were rounded and set in recesses in the tops of the columns, the nuts being let into recesses in the underside of the spider frames. Pivot bearings were cast on the top of the spider frames for the end posts of the several spans of the bridge; the spider frames were also connected to each other by the cross struts, tie rods, and a cast iron cornice; the whole being secured to the masonry by means of the guy rods (g. g.) All of the posts and struts for the bridge were used as they came from the foundry, no machine work being required. The difference in the lengths of the posts being adjusted by means of wrought iron washers placed on the pivots.

All the main and counter diagonals, also all of the diagonal tie braces, both in the bridge and the piers, had eyes at each end, but were connected and adjusted with screw swivels. All of the screw ends of the bolts in the bridge and piers, except the struts of the latter, were enlarged.

The contract with the Company required all of the wrought iron work of the bridge to be tested with a tensile strain of 22,400 lbs. per sectional inch; and as there were between 5,000 and 6,000, bolts it was rather a serious matter. During the operation of testing, several hundreds of the bolts broke in the welded parts, most of them in the eyes; only one broke in the screw part, a highly crystallized ¾ inch bolt.

I recollect one instance in which a full set of chord rods for one or two panels, broke while being tested; they had been welded, or rather an attempt had been made to weld them, and although before testing it could scarcely be seen where they had been united, so very smoothly and nicely had the work been executed, yet after being pulled apart it was scarcely perceptible where there had been any adhesion. On a subsequent occasion while experimenting with a working model of my testing machine, at the Locomotive and Machine Works of Trenton, N. J., I requested the foreman of the smiths' shop to procure a round bar of wrought iron one inch in diameter, about four feet long, and to have an eye formed at each end of the same; cautioning him to see that the welds were perfect. When he returned with the bar I asked, "Are you sure that the welds are pertect?" to which he replied, "I will guarantee them" The bar was placed in the machine and power applied until the force reached 16,000 lbs. when one of the eyes broke, and Maj. Anderson, of Fort Sumpter notoriety, who was witnessing the operation, narrowly escaped having his leg broken by the cross head flying back. Upon examining the fracture, not more than two-thirds of the weld was found to be sound; on seeing which, the Major remarked, "That shows the importance of having *all welded work* tested."

While testing wrought iron bolts I have noticed in some instances bars have been broken when under a strain of about 60,000 lbs. per square inch, presenting a fractured surface of fully one-third crystalline texture, the elongation of the bar being quite small. In one instance, two bars, each 12 feet long, were tested, the one after the other; each bar broke near the middle after elongating about 11 inches under a strain not exceeding 40,000 lbs. per square inch. At the point of fracture the bars were re-

duced probably 3-32nds of an inch in diameter, the surfaces of the fractured parts were entirely fibrous and were too hot to handle without burning the hands.

The Jordan Iron Bridge at the time of its completion was one of the longest, if not the longest in the United States. There were comparatively few Iron Truss Bridges in the country at that time, and they were looked upon rather in the light of an experiment than otherwise.

The first stone of the masonry for the bridge was laid August 27, 1856, and during the month of July, 1857, it was completed, and was tested with a load of 2,520 lbs. per foot lineal, or 112½ tons gross was placed upon one span and successively pushed and pulled over all the spans for the space of about one hour and a half, to the entrire satisfaction of the officers of the Company. This bridge has been in use about thirteen years; and I was recently informed by Joshua Hunt, Esq., the President, that it is now in perfect order, and has cost nothing thus far to keep the iron work in repair.

The extension of iron under a force of 22,400 lbs. to the square inch was uniformly about 1 16 of an inch to every five feet in length, and the contraction precisely the same upon the removal of the strain.

The results of the testing proved conclusively the uncertainty of welded work, and the reliability of screw bolts; and I have ever since felt it to be my duty to use as small an amount of the former as possible. I allow no welds to be made in either the lower chord rods, or the main and counter diagonals of my bridges. Of course I use screw nuts, some of which are made by welding, but the force exerted on the weld can never exceed the one-fourth of that on the bolt, and may answer its purpose even though not quite sound. The cutting of the thread, moreover, will test the soundness of the weld, which can readily be ascertained by inspection after the cutting. The breaking of a nut, however, rarely occurs, even though the power exerted should be greater than that which takes place in practical working.

While the second span was being erected I discovered some singular-looking spots on the webs of several of the posts, which upon examination proved to be sand flaws, commonly termed honey-combed, filled with a mixture of sulphur and plumbago. I had such posts removed, and at the request of the President of the Company, sent one of them—an end post—(see Fig. 11,) to Catasauqua, where it was placed in a horizontal position in

a hydraulic press, and subjected to a compressive strain of 160,000 lbs., which produced little or no deflection in it.

A defective intermediate post was placed in my own testing machine, and subjected to a compressive strain of about 53,700 lbs., which caused a downward deflection of the post of about two inches, more or less, from which it partially recovered on removing the strain.

At the foundry where cast, a sound intermediate post was placed upon props, (see Fig. 10,) blocks of wood were placed each side the vertical web at the centre, a rectangular mass of iron of 4,000 lbs. weight was laid on top the blocks, and was mounted by three men of about 150 lbs. each. The men then surged up and down awhile, breaking the vertical web from the bottom up to the cross web at about one foot from the centre of the post. Five men then got on, and after surging awhile broke it in two. Another of the same kind of posts was tried with precisely the same results. The last two experiments indicate a positive strain of more than 32,500 lbs., and a negative strain of more than 66,000 lbs. to the square inch, not taking the surging into account.

I built a bridge for the Central R. R. of New Jersey, at Bound Brook, the end bearings of the upper chord of which have neither been turned, planed, or had a tool on them, and yet these parts are constantly undergoing a compressive strain of 14,000 lbs. per square inch.

Another bridge of 92 feet spans on the line of the Newark and New York R. R., when loaded with 2,500 lbs. per foot lineal, on each track, produces a strain on the upper chord of 19,000 lbs. per square inch; in both cases the elasticity of the metal remains perfect. Several years ago I erected an iron public road bridge, across the Lehigh river at Easton, Pa.; the bridge consisted of two spans of 132 feet each; each span had three supporting trusses, there being two carriage-ways, and two outside footwalks; each carriage-way was 11½ feet wide, and each footwalk 4 feet wide. The floor beams and all parts acting by compression were of cast iron, and all those acting by tension of wrought iron. The joists and flooring were of wood. Over this bridge there has been a great deal of heavy teaming; the street railroad is also laid over it. I have been credibly informed that during the late civil war, the troops marched over it keeping step to the music of the fife and drum, and that, too, while the bridge was otherwise crowded with human beings. I thought it rather a foolhardy experiment, as it was quite light and not designed to be so

used. I now think that all such bridges should be constructed with such a contingency in view, for should one break down when so laden, the result would be terrible.

The facts I have stated prove beyond a doubt, in my opinion, the reliability of cast iron for compressive members in bridge construction, either alone as in an arch, or in combination with wrought iron or steel as in a truss.

Cast iron, it is true, is liable to defects such as unequal thickness in the sides of hollow columns, cold-shuts, honey-combs, etc., all of which can be readily detected by competent, practical men. Wrought iron also is liable to defects, as it comes from the mills or forges; it may be cold-short, or it may be imperfectly worked and welded, and when required to be worked into different forms the welds are quite uncertain.

From what I have observed and read in regard to the compressibility, tenacity, and elasticity of wrought and cast iron, I am led to infer that if a bar of each 1 foot long by 2 inches square be acted upon compressively the latter will yield the most at first, but as the pressure is increased it will yield less and less until its power of resistance becomes greater than that of the wrought iron, when the latter will give way.

It has been suggested to my mind that tensively wrought iron may have greater elastic power than cast, while compressively the latter may possess the greater. Tensively sponge has a very slight elastic power, but very great compressively. With india-rubber the case is just the reverse.

But the testing of cast iron in solid bars or masses is by no means, in my opinion, a fair test of its strength as used in bridge building. It is well known by practical iron workers that the outside or surface of castings is harder than the interior of the mass, and much stronger both tensively and compressively; consequently the casting of it in hollow cylinders and hollow squares, the H, the X, or cruciform, and various other shapes, adds greatly to its strength, (see Figs. 12, 13, 14, 15, 16 & 17,) each of which has a sectional area of one square inch, and a length of ten inches. According to Mr. Whipple's tables, the safe compressive load for columns indicated by the figures alluded to, varies from 13,000 lbs. for the square solid one, fig. 12, to 21,800 lbs. for the hollow cylinder, fig. 16. I am unable to state the tensile strength of the columns of the various forms alluded to, but am led to believe that the quality of metal

and area of section being the same, the greater the surface the greater the strength.

The advantages of cast iron as a material in bridge construction, consist not only in its great power of resistance to compressive forces, but also in its susceptibility of being cast into any possible shape desired, at the smallest cost; and the percentage of corrosion in cast iron is very much less than in wrought iron.

In order to illustrate the advantages afforded by the use of cast iron in bridge construction in place of wrought iron alone, I will compare the details of a bridge designed by Mr. Linville with one designed by myself; the photographs of the latter are hanging on your walls. By the "Linville Bridge," I mean that generally known as the "Keystone Co.'s Bridge," which is by some, *called a wrought iron bridge*. In this bridge the chords A A (Figs. 6 & 7) consist of eye bolts made of flat bar iron, connected at each panel with round pins (B B) of wrought iron or steel, on which rest the lower ends of the posts (M M), and to which are attached the main and counter diagonals H H & I. The upper chords (F F) are formed by placing between two horizontal plates, two H (h) and two ⌴ trough beams of wrought iron. [In a bridge of a similar character at Easton, Pa., the top and bottom plates of the chord vary from ¼ of an inch to ¾ of an inch, more or less, in thickness, and about 21 inches wide.] The angle blocks G G, which form the upper bearings of the main and counter diagonals are made of cast iron; they are hollow and are attached to the chord plates by means of dowel projections cast on their bottom sides, which fit into recesses cut into the plates for the purpose. The floor beams, which are of wood, rest either on the bottom or top chord plates.

In my bridge, (see Figs. 8 & 9) the lower chord is formed of six round bars of wrought iron (a a a, &c.) which are passed through the combination plate or angle block (b b) and are connected longitudinally with sleeve screw nuts (m m) and laterally with the plate (b b), the latter being held in position by the jam nuts (n n n).

The chord rods (a a a) being proportioned to the strain, the ends of the smaller ones are enlarged so as to screw into the sleeve nuts of the next larger in size.

The floor beams (c c), which are of wrought iron, are suspended from and bolted fast to the combination plates.

The upper chord (h. i. g.) is made of cast iron, and is hollow and cylindrical in form, excepting the part forming a cap over the post, which is also hollow, but of rectangular form and very thick. The cap is provided with angle bearings (P. P.) on top for the nuts or the heads of the main and counter diagonals (k. k. l. l.,) and beneath with suitable recess and bearing for the top of the post, and bearings on the sides for the lateral diagonal tie bolts (t. t.) and cross struts (s. s.).

The ends of the sections of the upper chords, and of the tops and bottoms of the intermediate posts, are turned off so as to afford good bearings at right angles with their axes.

In order to obtain greater stiffness in the posts and upper chords, they are made largest in the middle, and where, as in the present instance, the post is for a double cancel truss, a middle piece (e. e.) is inserted. This piece, it will be seen, has an opening for the passage of the main and counter diagonals. It is made very strong and the top and bottom parts close the hollow ends (f. & d.) of the shaft of the post, so that no moisture can enter. The ends of the main and counter diagonals are enlarged on account of cutting the screws.

In my bridge the lower chord-rods, although placed in position and bolted together, when there is no strain on them, are independent of each other, and should any of them, or the main and counter diagonals, break, they may be replaced without the necessity of falsework. All of the rods can be thoroughly protected with paint, and the bolts being round they present the smallest surface possible for corrosion or painting.

The only cross strain in a combination plate, is that of one set of main diagonals. The combination plate affords a safe support for the floor beams, and a square bearing for the bottoms of the intermediate posts, thereby rendering the *whole strength* of the *posts* available.

In my bridges no moisture can enter the posts, and the bearing being flat and at right angles to their axes, their whole strength is available.

It may be said a post of cast iron will not withstand the battering of an engine when it runs off the track. *No posts* can withstand such concussion, unless constructed for the express purpose, which would require such an amount of material as would prohibit their erection.

In my opinion every track of a railroad over a bridge should be protected with guard rails of iron, so arranged as to prevent the wheels leaving the track, by confining the flanges of the wheels of the cars in

position, the efficacy of which arrangement may be seen in the very short curves around which our street railroad cars pass with perfect safety.

Although foreign to the subject of bridges, still inasmuch as the strength of cast iron as a material for bridge and other building purposes is the matter in question, I think there will be no impropriety in asking, Without cast iron for gearing purposes, what would become of the countless factories, machine shops, rolling and other mills, which have caused our towns and cities to resound with the hum of life and activity? Or in what possible way can cast iron be more severely tested, than when used in the form of wheels for railway cars heavily loaded, and dashing along over rough railroads with the velocity of the wind? Yet there is more danger of the breaking of a wrought iron rail, than a cast iron wheel.

In the use of cast iron or other materials in bridge construction, it will not do to be governed by theory and figures alone; good judgment formed by observation and practical experience, is highly necessary in proportioning the various parts; for instance, we may choose between a column of 6 inches or 10 inches in diameter; in the first, the area necessary may require the sides of the column to be $\frac{1}{2}$ an inch thick, whereas the area of the latter would require the sides to be but $\frac{1}{8}$ of an inch thick, both of which are according to theory and calculation. Both experience and prudence would dictate the use of the smaller column as best calculated to withstand the vibration and shocks that might be looked for.

Although I consider it exceedingly unwise to reject cast iron for compressive purposes, instances may occur in which wrought iron might be preferable. In all such cases the engineer will of course be governed by circumstances.

The practical experience of most engineers and builders will justify me in the assertion that there is much more to be feared from defects in wrought iron used for tensile, than in cast iron used for compressive purposes.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

*Extracts from a paper read by* S. WHIPPLE, *Civil Engineer, Member of the Society.*

## ON TRUSS BRIDGE BUILDING.

My object in calling up the subject at this time is, to endeavor to correct some misapprehensions which seem to have been entertained in some quarters as to the position occupied by me in relation to this branch of the engineering profession.

I wish to notice a pamphlet by Charles Macdonald, Esq., of Pennsylvania, setting forth the merits of a certain plan of truss, called "*the Isometric.*" Among other plans with which comparisons are instituted, there is presented a diagram of a truss, which the author calls the "Whipple Truss," and another which he designates as the "Linville Truss." The former contains an important feature, *unlike* anything ever constructed, recommended, or even *tolerated* by me; while the latter is in general features the same as was used and recommended by me over twenty years ago, except that Mr. Linville has departed from my practice by using vertical posts at the ends instead of the triangular end panels of my adoption. The rectangular end panels are more expensive, and *may* have compensating advantages in certain cases.

Mr. Linville has also, according to Mr. Macdonald's diagram, given his diagonals a greater inclination than 45° from the vertical, a favorable modification, which has also been used by me for many years.

It is true that in my original publication I signified a partiality for the 45° inclination on account of its simplicity; still, on page 37 of that work, it is remarked that "when diagonals act by *tension* they may slightly approach the horizontal, and when by thrust, the perpendicular, without disadvantage." But neither by word nor act have I ever sanctioned the use of tension diagonals in connection with vertical posts with a less inclination than 45°.

Now, Mr. Macdonald represents what he designates as the "Whipple Truss," with diagonals inclining only 30° from the vertical.

I desire here to enter my emphatic protest against the imputation of ever having tolerated any such practice.

Col. Merrill, in his late work on "Iron Railroad Bridges," has introduced my name in the same unwarrantable connection. But he has coupled Mr. Murphy's name with mine, to bear part of the load, though I believe Mr. Murphy is as innocent in this respect as I profess to be.

But what of the Isometric? The name, at least, as applied to bridge trusses, is new, and euphonic withal. This is a truss with parallel chords *without* vertical members in the web: one of the general types discussed and compared in my publication of 1847 with reference to Fig. A., page 14.

The discussion with reference to that figure was upon the assumption of an inclination of 45° for diagonals, and not 30° as adopted in the "Isometrical." To this angle of 30° appear to be due the name and the distinguishing general feature of the plan.

As to any virtue that may be supposed to reside in this particular inclination of diagonals, namely, 30° with the vertical and 60° with the horizontal, if time shall allow, I will endeavor to show that it is a far greater departure from the theoretically *best* inclination than the angle of 45° assumed in my original investigations.

I am not aware that there had existed any examples of the parallel chord truss without verticals, prior to their construction by me over 20 years ago, with the important exception of the plank lattice bridge. This was first known to me under the name of "Town's Lattice Bridge," and it was a very cheap and serviceable bridge when properly constructed.

The Lattice contained the general principles of action contained in the Whipple "Cancel-truss without verticals" (with its uncouth designation) the "Warren Girder," the "Triangular," and the "Isometrical" Truss.

I have never learned that any one before myself ever attempted to point out in detail the principles of action in the Lattice truss, and the proper proportions of its parts. I had only seen it mentioned as the result of an "ingenious mode of constructing a *Deep Beam*," as it was called.

Whether the truss without verticals was originally suggested to me by the Lattice I am unable to say at this late hour. It may or may not have been. But somehow it occurred to me, apparently after the arch truss Fig. 8 (of Whipple's Bridge Building) had been discussed and compared with the truss *with* verticals, Fig. 7, that a plan in which every member

of the web system should do something in the way of advancing the weight toward the abutments, might possess advantages over one having vertical members merely to transfer the action of weight directly from chord to chord without advancing it at all horizontally.

Consequently Fig. A was constructed to correspond generally with Fig. 7, and a comparison instituted between the amounts of action upon material in the two, which showed a result in favor of truss without verticals, both over truss 7, and the arch truss Fig. 8, and the plan without verticals was adopted (by me) for wooden bridges especially.

But for iron bridges, in which I was inclined to the use of cast-iron for thrust members, the shorter length of vertical thrust pieces in connection with certain practical considerations, seemed to be a full offset against the theoretical advantage of the truss without verticals.

Still, if wrought iron is to be used exclusively for railroad bridges, as many engineers think it should be, it is not very unlikely that vertical members in the web will eventually be generally discarded, though the theoretical difference in the economy of the two systems is not so great that *practical* considerations may not often be an overbalance.

Mr. Macdonald's comparisons, like my own, show a superiority in general economy for the truss without verticals. But, in his case, the result is owing to a mistaken assumption as to the inclination of diagonals in the real Whipple truss, and to the loss of economy in the regular end panels of the Linville truss. Had he based his computations upon a genuine Whipple "Trapezoidal truss," as, for instance, his Linville diagram, with the end panels replaced by triangular ones, the result would not have appeared so disparaging to the latter, or so triumphant for the Isometric.

As a verification of this, if we take a truss of 10 panels, corresponding in length and depth with Fig. 46, page 180 of my book, we may form a truss similar to the Isometric, only the diagonals will incline a little more than 30° (a change favorable to the economy of the truss); and, estimating material upon the same basis as was done with regard to the trusses compared in the table, on page 182, we shall find the representative for tension and thrust material, each about 48.36, against tension 50.5, and thrust 46.94, for the truss Fig. 46—a difference merely nominal.

Again, taking the Isometric, as exhibited by Mr. Macdonald, with 14 panels, and the Trapezoid, with diagonals crossing two panels, with an inclination of 1.154 horizontal to 1 vertical reach, the representative numbers will be, for the

Isometric, 117.86 thrust material; 117.86 tension do.=235.72 Total.
Trapezoid, 115.77 " " 122.45 " " =238.27 "

being about 2 per cent. advantage for the latter on thrust material, and nearly 4 per cent. for the *former* on tension material; and a fraction over 1 per cent. average advantage for the Isometric.

Mr. Mcdonald figures 19 per cent. average advantage for the Isometric over the Linville, upon the *web system only;* which should be 6 to 7 per cent. on the whole truss—the web system comprising about $\frac{1}{3}$ of the material. My own figuring shows the average advantage of the Isometric to be $7\frac{8}{10}$ per cent., and of the Trapezoid about 6 $\frac{7}{10}$ per cent., over the Linville.

These results are obtained on the assumption that the material will sustain the same stress to the square inch, whether of thrust or tension, in one plan as in the other, which is generally true as to tension, and substantially so as to the upper chord. But, as to the web system, it will depend considerably upon the form and proportions of thrust pieces—a matter dependent upon the skill and judgment of the designer.

From the above statements, if my computations are correct (and they agree substantially with Mr. Macdonald's), it appears that the Isometric has no material theoretical advantage over the Trapezoid, with a *proper inclination of the diagonals.* But, on pages 14, 15, and 16 of my Bridge Building, it is shown that, with diagonals at 45°, in both cases, the truss without verticals requires 6 or 8 per cent. less material (at the same stress per square inch) than the truss *with* verticals; other conditions the same.

I obtain, also, about the same result from comparison of action upon Double Cancelled trusses of 16 panels, having diagonals at 45°. (See Figures 39 and 40, pages 141 and 146, Bridge Building.) This difference from results obtained in comparisons with the Isometric arrangement, arises from the fact that in the latter case we used a more favorable inclination for diagonals in the Trapezoid, and the less favorable one for the truss without verticals; for it is well known that tension diagonals act with best economy at 45°; and it is obvious that, at a *given stress to the inch*, as assumed in this case, the same must be true also of *thrust* diagonals. Hence 45° must give the best possible results for the truss without verticals, upon this hypothesis. In practice, however, in case of thrust diagonals, having no lateral support from end to end, according to the conclusion reached in page 161, Bridge Building, the best economy is

obtained by an inclination of about 35 1/4° (0.707 hor. to 1 vert.). Consequently, the best economy for thrust and tension diagonals, equally inclined, must be very near the mean of 35° for the one, and 45° for the other; that is, 40°.

Therefore, when we can obtain this inclination, or a near approximation to it, with the best proportion of length to depth of truss, and a desirable length of panel, we may rest satisfied that we have all the advantage the nature of the case admits of, in a truss without verticals. But when the above-named proportion and length of panel drive us to an inclination of thrust and tension diagonals in combination, greater than 45°, or less than 35°, should such cases ever occur, we may feel equally assured that the theoretical advantage of the system without verticals is of very trifling moment.

With regard to diagonals acting upon vertical posts, by increasing the inclination beyond 45°, though we lose somewhat on diagonals, we diminish the action on verticals at a greater ratio; whereas inclining at less than 45°, we lose on both classes of members. Hence, as a general rule, we should never, in this combination, use a less inclination than 45° from the vertical, but should adopt a greater, within certain limits, when practicable, with due regard to proper proportions of the truss in other respects.

I would in this connection call attention for a moment to what I regard as gross *malpractice*, in the case of most builders of Howe bridges. I consider it well established that thrust braces, considered independently, should not incline less than 35°, while at 45° they lose less than 10 per cent. in economy, while the expense of tension verticals is (in general) diminished in proportion to increase of horizontal reach of braces. Hence, by extending braces (in long spans) across two panels, nearly one half the expense of vertical bolts is saved, with a small increase in expense of braces.

But I fear I have become tedious.

Now, if I have accomplished anything valuable in the way of advancing the science of Bridge Construction, it consists more in the introduction of proper dimensions and proportions of parts in the truss, than the discovery of any new combinations which can be recommended as absolutely the best for all occasions.

The counterbraced arch truss, which has been extensively used with

good effect, was, I believe, first put in a feasible shape for iron bridges by me, and was thought to contain enough of novelty in its arrangement to justify the issuing of Letters Patent, which did not, however, greatly enrich the patentee.

The Trapezoidal truss, with and without verticals, though depending upon combinations so old that "the memory of man" (especially the present generation) "runneth not to the contrary," still, perhaps, owes something to me for economical form and proportions.

These three are all good plans, and each has its proper occasions where it may justly claim precedence over all others. On the contrary, each may be abused in careless and unskilful hands, so as to make a very inferior bridge. Mr. Macdonald and Col. Merrill, by unduly pitching up the diagonals used in connection with verticals, have made it appear that the Isometric and the Post trusses are vastly superior to what these gentlemen are pleased to term "*The* Whipple Truss;" and considering that the Isometric and the Post trusses are merely modifications (and not very favorable modifications either) of a type of truss *first* used and thoroughly discussed by me.

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XIX.

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NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

## *Extract from a paper read by* J. DUTTON STEELE, *Civil Engineer, and Member of the Society.*

### COMPRESSED AIR AS A MOTOR FOR SUBTERRANEAN RAILWAYS.

With reference to the leading characteristics of compressed air as a motor, I will proceed to consider its possible application to subterranean railways, and in doing so will assume as a basis for discussion, that we have a double track railway ten miles in length, with moderate curvature and reasonable grades, and an air pipe along the centre, of ten or twelve inches in diameter, with compressing machinery at either end driven by

steam, of sufficient capacity to maintain a pressure in the pipes of any given standard. Let us also assume that we have an endless wire rope passing along the centre of each track supported upon pulleys, and that it can be kept tight; and to compensate for its expansion and contraction by changes of temperature, that it is passed round double pulleys of larger diameter at stated intervals, say every half mile. These double pulleys may be arranged in vertical planes, so that the lower of each pair may move in its pedestal and be weighted to take up the slack, whilst those on the top, which receive the rope at the level of the rails, are fixed upon their axles, and provided with cranks for the application of power. I would next propose, that at each of these main pulley stations a stationary air engine is placed to move them, each engine drawing its power from the air main in the centre of the road. We should thus have our driving rope moved by twenty stationary engines, distributed along the line, acting in unison, connected by telegraphic signals, and working under the same pressure. It only remains to transfer that motion to the cars. The wire tramways now building in Europe for the transportation of ore and fuel in the mining and manufacturing districts, consist of endless wire ropes, supported upon pulleys, which are fixed to strong posts, and elevated more or less above the surface, with the moving power at the ends. Upon these wire ropes, boxes or cars are suspended at intervals, which contain the load, and which move with the rope, and are passed without difficulty over the pulleys, the opposite rope taking back the empty cars. The weight of the suspended load produces the necessary friction for transmitting the motion of the rope to the cars. The rope as proposed for a subterranean railway is in a better position for such use than in the wire tramway. Let us then suppose brakes dropped from the cars upon the driving ropes, so as to transfer only so much of the weight of the cars to the rope as may be necessary to communicate the motion, we should then have, by the use of brakes upon the rope, and brakes upon the wheels, the means of stopping and starting the cars at pleasure.

XIX.

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NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

*Extracts from a paper read by* F. H. COLLINGWOOD, *Civil Engineer, Member of the Society.*

## EXPERIMENTS ON THE POWER OF WATER TO TRANSPORT SAND IN SLUICES.

In discussing various plans for excavating and removing the sand from underneath the New York caisson of the East River Bridge, the question arose as to how much sand a given stream would carry, under the most favorable conditions as to slope, form of sluice, etc. By direction of Col. Roebling the following experiments were made for determining approximately these points :

| Number of Experiments. | Time. | Water, cu. inches. | Sand, cu. inches. | Vol. of Sand carried per 100 parts of water. | Velocity. (Approx.) | Suction of trough. | Remarks. |
|---|---|---|---|---|---|---|---|
| | m. s. | | | | In. per sec. | | |
| 1 | 15 00 | 51840 | 1944 | $3\frac{3}{4}$ | 20 | 1 in 80 | Sand left in trough had an inclination of 1 in 20. Insufficient supply of water. |
| 2 | 11 00 | 33696 | 5184 | $15\frac{1}{2}$ | $23\frac{1}{2}$ | 1 in 20 | Sand left in trough had an inclination of 1 in 11. Water insufficient. |
| 3 | 3 00 | 37584 | 9072 | 24 | $14\frac{1}{2}$ | 1 in 20 | Sand left in trough had an inclination of 1 in 11. Water increased. |
| 4 | 2 00 | 34992 | 12960 | 37 | 26 | 1 in 10 | Trough left clean. About $\frac{1}{3}$ more water than last. |
| 5 | 1 30 | 29808 | 18144 | 61 | $34\frac{1}{2}$ | 1 in 10 | Sand 6″ deep at upper end, but sloping irregularly. Evidently too much thrown in. Water increased about $\frac{1}{4}$ on last experiment. |
| 6 | 2 00 | 31752 | 16200 | 51 | 22 | 1 in 10 | Trough left clean. Water as in No. 4. |
| 7 | 1 25 | 31104 | 18144 | 58 | 23 | 1 in 10 | About $2\frac{1}{2}$″ of sand in middle of length of trough, sloping irregularly each way. Too much thrown in. Water same as No. 5, viz., full stream from a fire hydrant, through 150 feet of hose. |
| 8 | 1 14 | 33696 | 15552 | 46 | $24\frac{1}{2}$ | 1 in 15 | Water same as last; 6″ of sand at upper end of trough, sloping irregularly. Too much sand thrown in. |

The apparatus employed was very simple, consisting of a large cubical box, accurately levelled, and placed conveniently for the final reception of the water and sand. The sluices were troughs 20 feet long, having a wide hopper-like enlargement at their upper ends, into which the sand was thrown, and the water discharged. One of these was made 12 inches wide, with vertical sides, the other 4″ wide on the bottom, 12″ at top, and 12″ high.

Experiments Nos. 6 and 7 were made with the wide-bottomed sluice, but, beyond a difference in velocity, the results are not conclusive as to form.

Experiment No. 4, compared with No. 6, shows clearly in favor of the latter; but this is probably due to more sand being thrown in during No. 6, as we find Nos. 5 and 7 reversing this result.

From the slope assumed by the sand in the sluices in Nos. 2 and 3, viz., 1 in 11, it was inferred that an inclination of 1 in 10 would probably make the sluice clear itself, and this result was obtained in Nos. 4 and 6.

The practical difficulty seemed to be to graduate properly the quantity of sand thrown in, so as to get a maximum discharge. As the labor involved was considerable, the experiments were not continued long enough to arrive at *average* results. The fact was demonstrated, however, that 100 parts of water would carry at least 40 of sand.

The sand used was very coarse and heavy, with occasional small pebbles intermingled with it.

XX.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

At a meeting of the Society, Sept. 21, 1870.

Vice-President J. W. ADAMS, in the Chair.

## HISTORY OF THE IRON RAILS UPON THE MICHIGAN, SOUTHERN AND NORTHERN INDIANA RAILWAY.

A paper presented by Charles Paine, Civil Engineer, Member of the Society ; with remarks on the Construction and Wear of Rails, by J. Dutton Steele, Civil Engineer, Member of the Society.

About 330 miles of this line were laid down in the year 1851, and operated immediately thereafter with a considerable traffic; but, the Company being then engaged in the construction of branch lines, no accurate account of expenses or renewals was kept until the branches were finished, in 1857, when the length of track owned by the Company, including sidings, was 567 miles.

I have included sidings in the length of track and in all calculations of the averages of wear, because, taking into account the excessive service at the termini and principal stations, the sidings will require as much iron for renewals as an equal length of main line.

The gradients and curves upon this road are light, the maximum gradient 28 feet per mile, and the sharpest curves of about 1,900 feet radius, excepting a few short planes and curves upon the branch lines, which are more severe.

The iron rails first laid upon the road were nearly all of British manufacture, of 56 and 57 lbs. per yard, "Erie pattern," with a pear-shaped head, 3½ inches high and 4 inches base; about fifty miles, of similar section, from Brady's Bend, Pa., which proved dangerously brittle, having been the only American rails now known to have been laid in the first track. The British rails were made from piles apparently composed of only one kind of iron, presenting an even, granular fracture throughout the section, and were much better welded than any made in England or in America, which we have since procured to replace them. They were 15, 18 and 21 feet long—chiefly 18 feet; partly laid with cast iron and partly with wrought iron chairs; the joints opposite, and resting upon a single tie. The sleepers were mostly of white oak, laid 2½ feet apart centres; 8 feet long, 6 inches thick, and from 6 to 9 inches wide. The ballast was of sand, or very fine gravel; but the road bed was not thoroughly ballasted—in parts, not at all.

As would be expected from these conditions, the rails were rapidly bruised at the ends; so that as early as 1856 those laid previous to 1852 were in desperate need of repairs, and a force of smiths was in that year set at work mending them; by which means a large proportion of the rails, which had to be removed because of their bruised ends, were restored to the track. The condition of the main line was also helped, by taking the sound rails from sidings and branches, and replacing them with battered or mended rails, so that the necessity for the purchase of new rails for repairs was postponed.

Since 1859, the surface of the track has been maintained in excellent condition, and the road has been in as good order, in respect to depth of ballast, drainage, and prompt renewal of sleepers as any of the best lines in the United States; so that rails have had a fair chance to show good results in wear, if the nature of the metal from which they were made and the mode of its manufacture would permit. It would have been better for the track and for the rolling stock, if repairs had begun sooner, and if they had been more liberal in amount, at first; for the tables given here, which show what was done by way of repairs, do not fully indicate what

ought to have been done, but only what it was possible to get along with.

A considerable and judicious economy was effected by the mending of rails, instead of re-rolling them, since the cost of re-rolling has averaged, during the period included in this account, about $3,500 per mile, while the cost of repairing rails by hand has averaged about $600 per mile; the mended rail not being so good, of course, as the re-rolled rail, but serving the purpose of keeping the track in a condition of comparative smoothness.

On a part of the main line, 18 miles in length, which had already been re-laid with mended iron, where the grades were very light and few curves, it was found that the mended rails averaged a wear of twenty months before being taken up to be again repaired; on branches, they wore longer.

The metal laid down in renewing the track, except about 30 miles of British iron, has been chiefly re-rolled rails of 61 lbs. weight, per yard, with a pear-shaped head; 4 inches high and 4 inches wide on the base. About 50 miles were laid with fished joints, for which the section is of improper shape, and which, of course, did not do well; the remainder was laid with a modification of the "*Howe joint*," shown in the drawing attached to this paper. This joint has proved the best of any, upon a light, sandy ballast, the only material which was available upon this line, and one which requires that the joint should have the broadest and steadiest bearing upon it which can be devised. Reports of the condition of all the rails removed from the track, show that where the plate chair upon a single tie is in use, $\frac{64}{100}$ of the whole number are bruised at the ends only; whereas, upon the portions of the line where the Howe joint is laid $\frac{23}{100}$ of the whole are so bruised. Since 1858 the centres of the sleepers have been laid 2 feet apart; since 1864 the sleepers have been 9 feet long.

It will be observed in the tables that the rails of 1864 and 1865 proved exceptionally bad. Previous to 1864, the rails had been re-rolled in "two high" rolls, from solid piles of from $6\frac{1}{2}$ to $7\frac{1}{2}$ inches square (sometimes composed entirely of re-worked rails, sometimes with a head-flat of harder metal), into rails 21 feet long. At this period, the enormous cost of iron, owing to the rebellion and to the tariff, caused railway managers to seek for the cheapest quality which could be obtained; and although re-rolled rails were then evidently inferior to the rails first laid down, and

were wearing out with alarming rapidity, resort was had to "three high rolls," and to piles from 9 to 10 inches square, in which were from three to six pieces of old rails which had not been broken down into flats; and these piles were rolled out into rails 27 feet long. This mode of manufacture continued until near the close of 1867; by returning, then, to solid piles—in some reducing them in size, and by the use of raw puddle-bar between ths harder head-flat and the re-worked old rails—better welding has been secured, and the resulting wear has been much prolonged; yet these rails are not equal in quality to those made from 1860 to 1863. The length adopted for rails after 1865 was 24 feet. Since this time, it has been found that the larger the proportion of new metal introduced into the piles, the better have been the rails—a result probably due to the fact that a great part of the rails which were being re-rolled, having been re-worked once or twice before, had become quite unfit for making rails again. Although this experience of 1864–5 was convincing that the solid pile is better than one composed in part of old rails, not broken down, yet, as many rail makers and some engineers still maintained a contrary opinion, an experiment was afterwards made to settle the question. A lot, some hundreds of tons, of rails was made from piles in which there were three unworked pieces of old rails; and another lot was made from the same iron and according to the same specifications, at the same mill with the first lot, with only the difference that all the old rails used were first broken down into flats. These two lots of rails were laid down in situations where they would undergo similar wear, and at the end of one year the two classes were compared; of those made with old rails in the pile, one-twelfth of the number had been removed from the track, and many others were showing signs of disintegration; of the rails made from the solid piles, one fifty-secondth of the whole had been removed, and the remainder were apparently in good condition.

The tables appended to this history have been compiled from the annual reports and from the records of the Engineer's department. Excepting the first two or three years of the existence of the Railway Company, accurate accounts have been kept of the miles run each year, by the engines, including switching engines. For those years, the miles run by engines have been calculated from the traffic returns; from this account of the total number of miles run by engines has been deduced the average number of trains over each mile of the track, dividing the total miles

run by the total number of miles of road operated, including sidings. Upon the western division of the road, which is about 100 miles long, and the most severely worked of any part of the line, the miles run by engines have been recorded separately from the accounts of the other divisions: and as the traffic over this division is very uniform throughout its length, Table No. 3, which shows the experience of ten years upon it, is a very correct exhibit of the performance of re-rolled rails.

In considering these tables it should be remembered, as indeed Table No. 1 clearly reveals, that the life of all the iron has been prolonged to its farthest limit by repairing; this was more practicable with the first rails laid down than it is with modern ones; because, although from the imperfection of the joint used, they became battered at the ends, they remained sound in the middle, being more thoroughly welded. The rails now made are laid upon an improved joint; if they fail anywhere it reveals bad manufacture, and the imperfect welding generally extends throughout the length of the rail, rendering it useless to repair it—so that only about one half the number of rails formerly repaired in each year are now mended, although by improved machinery it can be done at less cost, and better.

I am aware that this account of an experience with iron rails will not have the interest which it would have possessed before steel rails were so generally adopted for the renewals upon heavily worked lines; yet, even now, there are engineers who need to be reinforced in their struggle against mistaken views of economy, and to these I offer this contribution, as *Memoires pour servir*.

The length of main track maintained after 1856 was 524 miles, the subtraction of this sum from the numbers in the column of "miles operated" will give the length of the sidings.

# Table No. 1.

*New and Repaired Rails laid down upon the whole Road.*

| Year. | Miles of Road Operated. | Miles of New Rails Laid Down. | | Miles of Rails Repaired. | | Miles of New and Repaired Rails Laid Down. | | Average Number of Trains over each mile in the Year. |
|---|---|---|---|---|---|---|---|---|
| | | In Year. | Total. | In Year. | Total. | In Year. | Total. | |
| 1852. | 330 | ..... | ..... | .... | .... | .... | .... | 3586 |
| 1853. | 334 | ..... | ..... | .... | .... | .... | .... | 4180 |
| 1854. | 340 | ..... | ..... | .... | .... | .... | .... | 4620 |
| 1855. | 340 | ..... | ..... | .... | .... | .... | .... | 4950 |
| 1856. | 343 | ..... | ..... | 30 | 30 | 30 | 30 | 4670 |
| 1857. | 567 | ..... | ..... | 65 | 95 | 65 | 95 | 3280 |
| 1858. | 574 | ..... | ..... | 86 | 181 | 86 | 181 | 2710 |
| 1859. | 574 | 6.96 | ..... | 84 | 265 | 91 | 272 | 2650 |
| 1860. | 574 | 8.62 | 15.58 | 79 | 344 | 88 | 360 | 2780 |
| 1861. | 574 | 10.18 | 25.76 | 80 | 424 | 90 | 450 | 3100 |
| 1862. | 574 | 20.87 | 46.63 | 95 | 519 | 116 | 566 | 3600 |
| 1863. | 574 | 23.56 | 70.19 | 86 | 605 | 110 | 676 | 3790 |
| 1864. | 570 | 39.05 | 109.24 | 97 | 702 | 136 | 812 | 3840 |
| 1865. | 575 | 46 18 | 155.42 | 94 | 796 | 140 | 952 | 3800 |
| 1866. | 578 | 91.03 | 246.45 | 81 | 877 | 172 | 1124 | 4130 |
| 1867. | 583 | 66.30 | 312.75 | 122 | 999 | 188 | 1312 | 4110 |
| 1868. | 587 | 87.33 | 400.08 | 138 | 1137 | 225 | 1537 | 4570 |
| 1869. | 596 | 94.85 | 494 93 | 73 | 1210 | 168 | 1705 | 5000 |

Note.—The length of main track maintained after 1856 was 524 miles; the subtraction of this sum from the numbers in the column of miles operated will give the length of the sidelings.

*Jan.* 1, 1870.—There remained on the branches 120 miles of the iron laid in 1856-7, all of which had been repaired.

The great increase in miles repaired in 1867 and 1868 is due to the increased length of the rails repaired.

In 1864 the use of a branch, four miles long, was suspended.

# Table No. 2.

*Traffic borne by the New Rails laid down upon the whole Road.*

| Year Jan. 1 to Dec. 31. | Miles of Rails Laid Down. | Miles of same Rails Remaining in Track Jan. 1, 1870. | Per cent. Remaining. | Per cent. Worn Out. | Average Number of Trains over each Mile, in the Year. | Average Number of Trains which have Passed Over Rails Remaining Jan. 1, 1870. |
|---|---|---|---|---|---|---|
| 1859. | 6.96 | 1.22 | 17.5 | 82.5 | 3300 | 50,000 |
| 1860. | 8 62 | 3.52 | 40.8 | 59.2 | 3480 | 46,500 |
| 1861. | 10.18 | 4.65 | 45.6 | 54.4 | 3880 | 43,000 |
| 1862. | 20.87 | 6.25 | 29.9 | 70.1 | 4500 | 38,500 |
| 1863. | 23.56 | 9.34 | 39.6 | 60.4 | 4740 | 34,000 |
| 1864. | 39.05 | 10.86 | 27.8 | 72.2 | 4800 | 29,500 |
| 1865. | 46.18 | 23.12 | 50.0 | 50.0 | 4800 | 24,500 |
| 1866. | 91.03 | 76.30 | 83.8 | 16.2 | 5160 | 19,500 |
| 1867. | 66.30 | 59 70 | 90.0 | 10.0 | 5140 | 14,500 |
| 1868. | 87.33 | 86.63 | 99.2 | 0.8 | 5710 | 8,900 |
| 1869. | 94.85 | All | .... | .... | 6100 | ..... |

This Table is calculated upon the assumption that upon one third of the whole length of the line, where very little new iron has been laid, only one half the average traffic is experienced. This assumption is very nearly correct, and rejecting the service upon this one third of the line from the calculation of averages, the above results are obtained.

# Table No. 3.

*Traffic borne by the New Rails laid down upon the Western Division.*

| Year Jan. 1 to Dec. 31. | Miles of Rails Laid Down. | Miles of same Rails Remaining in Track, Jan. 1, 1870. | Per cent. Remaining. | Per cent. Worn Out. | Average Number of Trains over each Mile in the Year. | Average Number of Trains which have Passed Over Rails Remaining Jan 1, 1870. |
|---|---|---|---|---|---|---|
| 1859. | 2.91 | None | .. | .. | 5396 | ..... |
| 1360. | 3.17 | 0 58 | 18 | 82 | 5350 | 72,000 |
| 1861. | 8.03 | 3.13 | 39 | 61 | 6170 | 66,000 |
| 1862. | 13.12 | 1.57 | 12 | 88 | 7260 | 59,500 |
| 1863. | 14 78 | 4.51 | 30 | 70 | 8020 | 52,500 |
| 1864. | 26.14 | 3.44 | 13 | 87 | 7530 | 44,500 |
| 1865. | 15.68 | 0.62 | 4 | 96 | 7470 | 37,000 |
| 1866. | 21.46 | 9.02 | 42 | 58 | 7910 | 29,500 |
| 1867. | 28.74 | 23.19 | 80 | 20 | 7910 | 21,500 |
| 1868. | 23 46 | 23.32 | 99 | 1 | 8890 | 13,500 |
| 1869. | 28.79 | 28.79 | 100 | .. | 9000 | ..... |

Upon this division, as upon the whole road, the traffic has been proportioned as follows:

| | |
|---|---|
| Freight trains | 0.5 |
| Passenger trains | 0.4 |
| Working trains | 0.1 |
| | 1.0 |

## REMARKS BY J. DUTTON STEELE, CIVIL ENGINEER, MEMBER OF THE SOCIETY.

Referring to the paper which has just been read on the wear of rails, etc., there is no doubt but it is a correct exposition of the experience on the road referred to, and as such is of value; but so various are the influences, both from the modes of manufacture and the local peculiarities to which rails are subjected, that statistics from other roads may be provided showing directly opposite results in several important particulars.

We have, in this paper, the principle strongly implied, if not directly expressed, that iron may become so highly refined by repeated workings, that it cannot be welded without the interposition of less pure layers—a popular theory among rail makers, but one which I apprehend is entirely in error. Indeed, I have heard this mode of making rails characterized as not welding their parts, but sticking them together with cinder. The best iron we have is made from scraps; we hear nothing of the difficulty of welding them, no matter how often they have been worked; the more worked the better. The celebrated Damascus blades, the highest quality of carbonized iron of which we have any knowledge, is said to be made of wire; and the same principle is acknowledged in our country, where wire ropes are much used. When superior iron is needed it is made from worn-out wire ropes; though more care is required to weld pure than impure iron, particularly where it is worked in large masses. Those who were connected with the early railroad experience in this country have a pleasant recollection of the double-refined Eba-Vale rails, which were among our first importations. Unfortunately, for the rail interest, when worn out as rails they were too valuable for re-conversion, and found their way into car-axles and other similar uses. The manufacturers of these higher qualities of iron found no difficulty in welding them, though the rail makers would sandwich them with their own poor stuff, if they were allowed to do so.

In a somewhat extended experience upon one of the largest freight roads in this country, it was my practice, for many years, to have the old rails reconverted, without any admixture of new iron: the best rails, such as the Eba-Vale, were selected for the heads, and the inferior for the flanges: all were broken down into slabs and thoroughly welded;

and, to secure as perfect a weld as possible, an English mode of effecting the same object was adopted, that of taking upon the rail piles two welding heats, by passing them several times through the rolls, after the first heat, and returning them to the furnace before they were finally drawn into rails. The result was better rails than were obtained by any other mode; better, even, than new.

I may here refer to what I apprehend to be a prevalent error as to the use of hard granular iron for the heads of rails. The Eba-Vale iron, which produced such satisfactory results, was not of that character; it was a well worked fibrous iron, and I believe all the best results have been produced from iron of that character in the heads. Some fifteen years since, an experiment was made under my observation, bearing upon this point: Rails made of fibrous and granular iron were laid alternately upon a heavy freight-bearing road; at the end of six months the fibrous heads showed the most marks of wear; at the end of twelve months the granular heads began to break up, and the result was that the soft, fibrous rails wore out two of the hard granular.

In the early railroad experience a patent was taken out in England for making the heads of rails of granular iron, and at least two patents have since been taken out in this country for the same object; but all with the same result—all have passed into oblivion, under the test of practice. There are several problems in the wear of rails which may be worthy of note. We all remember what a run the double-headed rail had in England, and how signal has been its failure; the first head subjected to the action of the wheels became granulated and its tensile strength destroyed, so that when the rails were inverted they broke.

True to the same principle, we find that any cause which changes the position of rails in the tracks, so as to alter the bearing of the wheels upon them, causes their destruction. If they are reversed side for side to the flanges, they wear out quickly, and even if they are taken up from one point in the road and laid down in another, by which means the bearing of the wheels upon them is, of necessity, more or less changed, the granulated surface is broken up, and their durability is decreased.

XXI.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

At a meeting of the Society, Dec. 7th, 1870.

## DESCRIPTION OF THE "PLENUM PNEUMATIC PROCESS" AS APPLIED IN FOUNDING THE PIERS OF THE ILLINOIS AND ST. LOUIS BRIDGE, AT ST. LOUIS, MO.

A paper presented by Mr. MILNOR ROBERTS, Civil Engineer, Member of the Society.

THE necessity for a bridge across the Mississippi river at St. Louis has long been acknowledged, and various projects have been discussed for many years, especially after the completion of several railroad lines leading to St. Louis from the East, and of others partially finished westward; but none of them assumed practical shape till the year 1864, when an Act of the Legislature of the State of Missouri was passed, incorporating the St. Louis and Illinois Bridge Company, with authority to construct a bridge over the Mississippi at the city of St. Louis, which was in 1865 incorporated by the State of Illinois, and it was also sanctioned by Act of Congress, in 1866, which enacted "that the bridge authorized shall not be a suspension bridge or a draw bridge, but shall be constructed with continuous or unbroken spans, and subject to these conditions: *First*, that the lowest part of the bridge, or bottom chord, shall not be less than fifty feet above the City Directrix* at its greatest span. *Second*, that it shall

* The City Directrix is 33′ 8″ above low-water mark.

have at least one span five hundred feet in the clear, or two spans of three hundred and fifty clear of abutments. If the two latter spans be used, the one over the main steamboat channel shall be fifty feet above the City Directrix (measured at the centre of the span). *Third*, no span over the water at low-water mark shall be less than two hundred feet in the clear of abutments."

In 1867 the State of Illinois granted an act of incorporation to another company for the purpose of constructing a bridge opposite St. Louis.

Each of these independent companies made locations, and devised plans for bridges to cross the river, one near the upper part of the city limits, the other, centrally, opposite Washington Avenue, with structure essentially different.

In August, 1867, at the instance of the friends of the Illinois and St. Louis Company, chartered by the State of Illinois, a Convention of Civil Engineers, twenty-seven in number, met in St. Louis, and discussed the merits of several plans proposed, the conclusion of the Convention being in favor of the upper location, with two spans of 368 feet each, preferring it to the plan of 500 feet spans, which had been designed and proposed by Capt. James B. Eads, C. E., and adopted by the other Bridge Company. The proceedings and report of the Board of Civil Engineers thus convened were very interesting, and were soon after published in an elaborate pamphlet, containing the data and reasoning which led them to criticise and condemn the undertaking of a bridge with 500 feet spans: "On account of the difficulty of procuring suitable materials of the proper form, size, and workmanship required to meet the extraordinary strains to which some of the members of the truss would be subjected, the increased hazard of its construction and maintenance, the large additional cost of the whole structure by the use of the long span, and because the necessities of this case do not require the use of one of such great length, for which there is no engineering precedent."

In the face of this decision, Capt. Eads, sustained by the directors of the original company, persevered in pressing forward the work he had undertaken, and in his report of May, 1868, answered in the most satisfactory and conclusive manner all the objections which the Convention of Engineers had offered to his location and general design.

Meanwhile, in March, 1868, the rival Bridge Companies having arranged their difficulties, an act was passed consolidating the two companies, and

in July, 1868, the act of consolidation was recognized and sanctioned by Congress, and all the powers of the two became vested in the present Illinois and St. Louis Bridge Company.

In the summer of 1868, Capt. Eads, the chief engineer of the bridge, was peremptorily ordered by his physician to Europe on account of ill health. The financial affairs of the company were not yet sufficiently advanced to warrant the active prosecution of the work. It was not till the spring of 1869, when Capt. Eads returned from Europe, much improved in health, that the finances were placed upon a secure footing, when the directors authorized the resumption and vigorous prosecution of the work.

During the stay of Capt. Eads in Europe, he embraced every opportunity which his health would permit to examine important bridge constructions, especially in connection with deep pier foundations. In the report of the Chief Engineer, made to the Board of Directors, in September, 1869, he thus refers to this subject: "During my visit to Europe last winter, I had an opportunity of witnessing the operation of sinking masonry piers by the *plenum pneumatic* process, as practised by the engineers on the continent of Europe, and I there became satisfied that, with the improvements made in it by them, many of which are unpublished, I could sink the piers of your bridge quite as safely, as expeditiously, and more economically than by the method I had intended to use. In France and England I was so fortunate as to be permitted to exchange views upon this subject with several of the most distinguished engineers in the profession, and my opinions upon this, the most important question in the construction of your bridge, were fully confirmed as a result of those interviews."

It was not until May, 1869, that it was finally determined to adopt the *plenum pneumatic* plan, and to proceed with both piers simultaneously, or as nearly so as was practicable.

The report just quoted states that. "In adopting this method of sinking the piers, it was necessary to mature plans and details of an entirely new type for the necessary caissons and floating appliances, and to design and construct machinery, purchases, etc., quite different from what had been intended."

The problem was, to sink two piers in the Mississippi river, each about five hundred feet from the shore, and about five hundred feet apart in a

stream of rapid current, varying at different stages of the river from five to nine miles an hour, with a fluctuating depth of water varying from ten to seventy feet, or more, through a body of sand varying in depth from eighty feet to only a few feet above the rock bed; the rock bed being, at ordinary stages of the river, ninety-five feet below the surface of the water at the east pier, and sixty-seven feet at the west pier.

The method of safely and speedily accomplishing this result, and the designing of the various plans and mechanical contrivances necessary to effect it, demanded a vast amount of careful thought, while the ordering and preparation of the different materials and appliances required great executive skill and energy.

Boats, barges, engines, water-pumps, air-pumps, sand-pumps, travellers, piles, pile-engines, masonry, timber, iron, bolts, etc., for the large caissons, had to be planned and provided, and an extensive and strong system of protection-piles arranged above the site of each pier; blacksmith and machine-shops had to be erected, and the ship-building yard at Carondelet, where so many iron-clads were constructed in such a marvellously short space of time at the commencement of the civil war, under the direction of Capt. Eads, was again brought into requisition for the construction of the iron caissons for the two piers.

## Borings, Etc.

To ascertain the depth to the rock and the kind of material to be penetrated by the caissons, soundings were made by means of cast-iron pipes, which were sunk by removing the sand from the interior with sand-pumps. These soundings were made from barges well anchored and secured with side cables, so as to maintain the pipes in the same vertical position. This required considerable labor and watchfulness, and was more than once interrupted by floods; but complete success was at last achieved, and it thus became known in advance of further operations that the material to be encountered at both piers consisted of coarse and fine sand, with a few small veins of gravel.

The depth of the deposit in the river depends on the stage of the water; in low water, when the stream has its minimum velocity, the depth of sand is about 80 feet, varying only a few feet in depth in the width of the stream, which is then reduced to about 1,600 feet; this being the narrowest point in the Mississippi river; whilst in the highest floods there

can be no doubt, that the sand is moved by the current down to the rock bed. Experience, during the few months occupied in the sinking of the piers, has demonstrated that a rise of only about 16 feet on top of the ordinary ten-feet flow above extreme low water, has scoured out more than 40 feet of sand; and the rock bed upon which the caissons finally rested, exhibited a smooth, water-worn surface. There is therefore no longer a question either of the propriety or of the absolute necessity of the plan urged by Captain Eads, of founding the piers on the rock. His judgment on this vital point was questioned by many intelligent engineers, but in justice to them it is fair to recollect that they had not the opportunities which he had enjoyed and so well employed for understanding the powerful action of this immense water flow.

To those who have only had experience with our Eastern rivers, the fact that such formidable changes from floods take place in the regimen of the Mississippi, must appear very striking. It is now obvious to all who are familiar with the operations in the river at this point, that a bridge resting upon piers founded materially short of the rock, as many proposed and advocated, would have been liable to total destruction in the first high flood.

### Breakwaters.

Extensive and costly breakwaters constitute an essential feature. Two large steam pile-drivers were constructed and the work above the site of the Eastern pier was begun about the 12th of August, having been delayed by the extraordinary continuance of an unusually high spring flood. The driving of the piles was commenced in 47 feet of water, with a subsiding river, but a few days thereafter another rise of five feet, which covered the tops of the piles then driven caused the work to be again suspended.

Ordinarily at that season of the year there should have been ten or twelve feet less water, and perhaps fifteen or more less scour. This would have given twenty-five feet or more less depth of water to work in, which would have greatly facilitated the work. The piles were about 70 feet in length. The unusual depth of water was not the only cause of detention; during a rise of the river, when the water is already very high, such quantities of drift-wood are floated down that it is very difficult to anchor the pile-driving boats.

The breakwater is formed by numerous piles planned in the form of an inverted V, the apex extending about 300 feet above the pier, and widened

at the lower end to nearly 200 feet, forming a protection for the caisson and the barges which contain the engines, machinery, etc., one on each side of the pier, as well as for the stone barges.

Each breakwater was further secured against the effects of ice by a large quantity of heavy riprap dropped in above the apex, and by a strong, heavy apron of white oak timbers covered and strengthened with 4-inch plank, let down on each side so as to stand at an angle of about 45 degrees, with the lower side resting on the sand and the upper side firmly bolted and secured to and braced against the outer row of piles. This is believed to be a novel feature in protection-piling, and it has answered its intended purpose admirably. Above this apron the piles were also covered on the outer side with oak plank, against which the ice and drift-wood rubbed harmlessly.

A short distance above the apex of the breakwater, a bunch of piles was driven, and above that a heavy anchor, composed of an old boiler shell, weighted with iron ore, was imbedded in the sand. From this passed a heavy wire cable, 2¼ inches diameter, to the bunch of piles and thence to the main breakwater; the piles of which were strongly braced by white oak lateral braces. From this protection system there extended afterward two strong wire cables, one to each side of the caisson.

### Guide-Piles.

Around the site of the pier were sunk ten large guide-piles, each three and a half feet in diameter, composed of old boiler shells at the lower end and timbers above, leaving a hollow or space in the middle of each, through which the sand was pumped out, so that it could be sunk to any desired depth. They were 83 feet long, sunk about 15 feet into the sand when the water was about 35 feet deep, and extended 33 feet above the surface of the water, and were all strongly braced together at the top.

Ten large screws, 3 inches in diameter, each 25 feet long, were supported from the top frames on these piles. They were arranged so that other links were added as the caisson descended. These screws were used to regulate the descent of the caisson and prevent any tilting until it should be fairly in the sand.

### Boats for Pumps and Machinery.

Two large boats, each 215 feet long, 34 feet beam, and 7 feet hold, were constructed for each pier, one ranged on either side just outside of the

guide-piles; these contained the machinery for sinking the piers with the caissons, and for hoisting and laying the stone. There were six large steam boilers, four of them arranged in two double batteries, and the others in two single batteries, on each boat; twelve boilers in all.

### Air-pumps, Etc.

Four air pumps, 4 feet stroke and 14 inches diameter of cylinders, driven by two independent engines, 24 inch stroke and 20 inch diameter of cylinders, are on one of the boats at each pier.

The engines on the other boat at each pier are used in hoisting and laying stone, etc., and in working the water-pumps and sand-pumps.

### Machinery for Laying Stone.

This machinery is built upon the boats, alike on each, so that each can take up stone from the stone barges lying outside, and transfer it rapidly to the pier by travellers, six on each boat. This frame-work is about fifty feet high, and supports six wire cables, two and one-fourth inches diameter, on each boat, and upon each cable is arranged a traveller. Each traveller is capable of transporting a seven-ton stone one hundred feet. They are worked by hydraulic rams when hoisting and lowering the stone, and by simple gearing when transporting it. One engine on each boat works the six travellers; there are six hydraulic jacks, of 10 feet stroke and 5 inch diameter, with two hydraulic rams required for supplying them with water, at a pressure of 1,600 pounds per square inch on each boat. Each traveller is easily controlled by one man, and, with all working, twelve stones could be raised and placed in position in each pier at the same time. Fourteen thousand seven hundred and eighty feet of wire rope were required for these twenty-four travellers.

The travellers work perfectly, and with them three hundred cubic yards of stone have been handled and laid on one pier in a day.

### Caissons.

The caissons were built by contract, at Carondelet, the Company furnishing the iron and rivets. They are composed of wrought iron. The larger one at the East pier is 82 feet long by 60 feet wide, the other 82 feet long by 48 feet wide. The air-chambers which constitute the lower portions of both caissons are 9 feet in height, and their sides are formed of $\frac{3}{4}$ inch

plate iron in the larger, and $\frac{5}{8}$ inch in the smaller. The designs of both are quite similar, except that the smaller has but five air-locks, while the larger has seven. A brief description of the larger air-chamber, at the East pier, may serve for both. The iron plates forming its roof (and at the same time the floor for the masonry) are of $\frac{1}{2}$ inch thickness. Transversely over this are placed thirteen wrought iron girders, each five feet high, which are securely riveted to it at intervals of five and a-half feet, and made of $\frac{1}{2}$ inch plate iron, with a top chord of $5 \times 7\frac{1}{2}$ inches of riveted plates.

Beneath the roof, within the air-chamber, are placed two lines of solid white oak girders, running at right angles to the iron girders above, dividing the entire area of the air-chamber into three nearly equal rooms, communication between the three divisions being through opens left for this purpose through the wooden girders. These timber girders were allowed to rest upon the sand, giving support to the roof and iron girders, from below, at equidistant points in the length of the iron girders. The sides of the air-chambers are strongly braced, to resist the pressure of the sand, with plate iron brackets, stiffened with angle iron, under each girder, on each side, in each of the three divisions or rooms. Between the brackets, within two feet of the bottom, is placed, all around the inside of the caisson, a course of strong timbers, the bottom of which is level with the bottom of the timber girders already described, and which also rest upon the sand. The area of bearing surface of this course of timber, and of the two girders, is 850 square feet. The support given by this surface of timber resting upon the sand, together with the buoyant power of the compressed air in the chamber, and the friction of sand on the sides of the caisson, served to sustain the pier in its gradual descent with its load of masonry, as the sand was removed, till it touched the rock.

### Manner of Sinking the Caisson, Air-locks, Etc.

The caisson, when launched at Carondelet (on the 18th of October, 1869), had a false bottom sufficiently water-tight to float it with a draught of $3\frac{1}{2}$ feet; it was towed to its position between the guide-piles on the same day of the launch, the two guide-piles at the lower end not being put in until after the caisson was in place. It was then attached to the large screws already mentioned, and as the compressed air was gradually pumped into the chamber, the false bottom, in three parts, became loosened,

and was then hauled out of the way, and the laying of masonry was begun on the 25th of October, at which time the water was 43 feet deep between the guide-piles. The masonry was first laid in the spaces between the iron girders, and, after reaching to their top, 5 feet above the iron roof of the chamber, the masonry was laid regularly over the girders and fitted around the air-locks.

### Air-Locks.

The air-locks are a very important feature. In the larger or eastern caisson there are seven, which were used for the entrance to and exit from the air-chamber, for men and materials. During the progress of the work and the sinking of the caissons, hundreds of visitors, of both sexes, passed, by the centre air-lock, into the air-chamber, and witnessed the operation of pumping out the sand and settling the piers.

The air-locks have heretofore been placed above the surface of the water, and ingress to the air-chambers obtained through large vertical iron pipes leading through the masonry. In these caissons the air-locks are placed below, within the roof of the air-chamber, and access is had to them through open air-shafts built up in the masonry. This change makes an important saving in the cost, avoids the delay caused by constantly adding new joints of pipes under the air-locks as the pier descends, and affords much greater convenience and safety and saving of time in introducing materials and workmen (and visitors) to the chamber.

The air-locks are circular vertical chambers from five to five and a half feet in diameter, and of various heights, from six to twelve feet. They are made of one-half inch plate iron. They are provided with two doors, one opening into the open air-shaft, and one into the air-chamber. The first door in opening swings into the air-lock, and the other into the air-chamber. The air-chamber being filled with compressed air, one or other of the doors remains closed. Either one being closed, the pressure of the air tends to keep it closed, but leaves the other free. The door leading to the air-chamber being closed, we enter the air-lock through the outer door, and close it behind us. A cock is then opened communicating with the air-chamber, and the air-lock is rapidly filled with compressed air. This equalizes the pressure on both sides of the inner door, and it can at once be opened, and we then enter the air-chamber, where we find the men at work in the compressed air. To return to the open air we re-enter the air-lock, close the inner door, and then open another cock,

which allows the compressed air in the air-lock quickly to escape. This relieves the outer door of the pressure that was against it, and it can at once be opened for our exit. One door or the other is always free to open. To open both doors at once in a hundred feet depth of water would require an enormous force (about 30,000 lbs.) to be applied to the one on which the air-pressure was acting at the time. This gives great security to those within the air-chamber against the carelessness or ignorance of those passing out or in.

[On the east pier men have worked at the depth of 110½ feet below the surface of the water, though under such a pressure — about 48 lbs. to the square inch — they were only allowed to work one hour at a time, three times a day.]

### Building the Masonry and Sinking the Pier.

As the weight of the masonry was added, the screws were gradually turned, with levers, by a gang of hands, with an intelligent foreman stationed on the upper frame-work, the screws being used chiefly to counteract any irregularities in the weight of the masonry on different parts of the caisson, though the ten were capable of sustaining without danger a strain of over 300 tons.

As the caisson descended, the river at the same time was gradually falling, though occasionally fluctuating, sometimes rising. A record was kept (by one of three civil engineers in charge every moment during the entire twenty-four hours), showing, at intervals of an hour, the condition of affairs. The steam-pressure, number of revolutions of the engine, air-pressure, draught of caisson at each of the four corners and ends, gauge, height of the river, temperature of the atmosphere, kind of weather, working of the hydraulic rams and travellers, and all unusual occurrences and accidents. Whenever the thermometer fell to 28°, or lower, the laying of masonry was suspended, also during considerable rains and snows, but the detention from these causes was not less than twenty days during the four months occupied in sinking the pier to the rock. Constant care and watchfulness on the part of the civil engineers in charge and of the Superintendent of Construction, with relays of foremen of machinery, steam engineers, men at the travellers, etc., prevented any serious accident or material delay, excepting as above, during the progress of the work. The most critical period was just prior to reaching the

sand, before any aid could be derived therefrom in steadying and supporting the caisson with its heavy weight of masonry, and when so much depended on maintaining regular and sufficient support from the air in the chamber, and in keeping an even strain on the screws. At the time the bottom or cutting edge of the caisson touched the sand (which was highest on the eastern side), there was an average of about 35 feet depth of water above the sand. As soon as one side fairly rested on the sand, workmen were sent in to level off the highest points by filling it into the low places; and in a few days thereafter, when the caisson was imbedded all around, the screws were removed. Thenceforth the vertical descent and correct position of the caisson were maintained by regulating the air-pressure and removing more sand from the side or end that was highest at the time.

As the mass descended, and course after course of masonry was built, the wrought iron skin of the caisson was increased in height by riveting on additional plates of iron, so that the laying of masonry and the raising of the outer rim of the caisson proceeded simultaneously, it being necessary to keep the top of the caisson some feet above the surface of the water to allow for sudden rises in the river, and for the constantly increasing draught caused by the daily increment of weight of the masonry and caisson.

[Experience in the sinking of the East pier led to a change of plan in the West pier caisson, by which the iron skin was left off at the height of 29 feet above the bottom of the caisson; the interior of the open shafts being lined with jointed, nearly water-tight plank, which kept out most of the leakage water permeating through the masonry. This system of plank-lining was also introduced into the upper portions of the shafts on the East pier.]

### Sand-Pumps.

The sand-pumps were placed in the air-chamber, and their suction-pipes, extended by flexible hose, reached to the sand; the vertical pipes passed up through the wrought iron ceiling of the air-chamber and were carried up the shafts to a sufficient height above the top of the caisson to discharge the sand and water into the river. As the caisson was raised, new sections of pipe were added. Seven sand-pumps were used in the caisson of the Eastern, and five in that of the Western pier. These pumps are of very simple but novel construction, never having been used before.

Pumps of sizes varying from 3 to 5 inch bore were tested, and very good results were obtained from those of from $3\frac{1}{2}$ to 4 inch bore. Gravel stones, as large as could enter (over two inches in diameter), were freely discharged.

As there are no working parts in its construction, this plan of sand-pump is not liable to get out of order save from the wearing away at the annular jet. The principle on which the pump acts is somewhat similar to that of Giffard's Injector, water being used instead of steam. A stream of water is forced down through one pipe and caused to discharge near the sand into another in an annular jet, and in an upward direction. The jet creates a vacuum below it by which the sand is drawn into the second pipe or pump, the lower end of which is in the sand and water, and the force of the jet drives the sand on upward to the horizontal discharging-pipe above the surface of the river as soon as it passes through the annular opening in the jet.

The superiority (as it is believed) of this pump over all others capable of pumping sand and gravel, consists in its being supplied with the requisite amount of water for keeping the sand in a fluid condition, while the suction-pipe is inserted directly in the sand. With other pumps the quantity of sand cannot be regulated, and it is liable to be drawn in in such quantities as to choke up the pipes and working parts of the pump, the water drawn in with the sand not being sufficient to keep it fluid. The weight of the column set in motion by the pump is consequently subject to constant variation, as it has more or less solid material in it; and when the column is raised by atmospheric pressure (vacuum), and a lift of only twelve or fifteen feet attempted, the pump may cease to lift the column, it being so much heavier than water because of having so much sand in it. In this case, if the suction-pipe has a foot-valve at the lower end of it, as most centrifugal pumps have, the sand falls back on it, and the pipe must be taken out to empty it of its contents. When too much sand is in the column above the ordinary pumps the pipe is liable to be overloaded with it, the action of the pump ceases, and the contents must be removed before the pump will again work. If the water-jet in the sand-pump we have used fails to discharge the sand, no choking up of the pump can occur. There is nothing in the construction of it to prevent the sand from running back when the jet stops, and if the jet is strong enough it will raise it to any height. Those at the East pier worked perfectly when the discharge-pipe was 120 feet in vertical height above the jet.

One powerful steam-pump was required for working simultaneously two sand-pumps. Generally two sand-pumps, sometimes three, were working at the same time. It usually required a gang of six to seven men to shovel the sand and manage one sand-pump.

The importance of avoiding, in a work of this kind, the many inconveniences and delays which dredging-machines would be liable to cause, if required to lift sand from seventy-five feet to one hundred and twenty feet in height in immediate proximity to extensive masonry operations will be readily appreciated by all engineers.

The entire success of the operation of removing the sand from our deep caissons by means of this system of sand-pumps presents a strong argument for their introduction wherever similar material may be encountered in founding deep piers.

## Masonry.

The masonry of the piers and abutments is of magnesian limestone, from the Grafton quarries, about 45 miles above St. Louis, laid in hydraulic cement, in courses of from 18 to 30 inches in thickness. From two feet below low-water mark the exterior of the piers and abutments will be of quarry-faced granite up to high-water mark, and of pointed-faced granite thence to the top.

Since the sinking of the piers to the rock, the air-chambers and the shafts have been filled with concrete, forming a solid mass composed of broken stone, mixed with hydraulic cement, extending from the air-chamber up to the level of the top of the masonry. In a short time the laying of masonry will be resumed, and it will then be extended over the concreted shafts, forming one unbroken mass.

The base of the Eastern pier is just the size of the caisson, 82 feet long by 60 feet wide, gradually tapered by offsets on each side. The Western pier is the same length by 48 feet wide. The Eastern pier at the height of ten feet above low-water mark will be 97 feet, and the Western pier 69 feet above the rock. The larger one covers an area of 4,020, and the other, 3,360 square feet. At ten feet above low-water mark each pier is 78 feet in length by 38 feet in width, and at that point each will contain a sectional area of 2,600 square feet.

The amount of masonry, brick-work, and concrete required to bring these piers to ten feet above low-water mark is about 21,000 cubic yards.

### Abutments.

The western abutment has been founded on the limestone rock at the depth of 13 feet below low-water mark, and built up to an average height of 17 feet above. Although it was not originally designed to sink the eastern abutment to the rock, which by careful sounding has been found to be about 94 feet below low-water mark, or 8 feet lower than the rock at the Eastern pier, the complete success attending the method adopted at the piers has led to a change of plan, and it has been decided to employ a caisson on the plenum pneumatic plan, and the same general system for sinking it as that used at the piers, modified and rendered less costly in construction by the substitution of timber for much of the iron work of the air-chamber, the iron skin of the caisson not being carried over 20 feet above the air-chamber, depending on the masonry and air-shafts (made nearly water-tight) for preventing serious leakage.

The caisson for the abutment is now in the course of construction, at Carondelet, on the same ways from which the pier caissons were launched, and it is expected will be completed in August. Meanwhile the necessary preparations in connection with the sinking of the east abutment and for the handling and laying of the stone, etc., are going forward; and it is anticipated that the abutment will reach the rock in December next, and that the masonry will be pushed on all the piers and abutments so as to be ready for commencing the erection of the superstructure early next spring.

A detailed account of the varied experience derived during the sinking of the two piers of this bridge cannot be looked for in a paper of this kind, prepared at short notice; it belongs properly to a yet unwritten history of this structure, which should be given to the profession at a future time. Rarely, in the accounts of bridge engineering, has there been a bolder scheme, or one more thoughtfully or more scientifically considered and arranged in advance, or more beautifully and successfully executed, than the designing, building, and sinking of these two piers in the Mississippi river, founded on the rock in such an unusual depth of water, and constructed and rendered secure in so short a period. The first stone was laid in the East pier on the 25th of October, 1869, and on the 28th of February, 1870, the bottom edge of the caisson touched the rock, 94 feet below the surface of the river as it stood on that day, being only about four months, including all delays and stoppages; and on the

28th of March, less than one month later, the west caisson also touched the rock, 78 feet below the surface of the river as it then stood, and only 72 days from the time the first stone was laid on it, January 15th, 1870. The masonry built on these piers during the above brief period amounted to about 24,000 tons on the East pier, and about 16,000 tons on the West pier, all of which was regularly laid in hydraulic cement, the whole now forming two massive piers, a fitting foundation for the immense superstructure soon to be reared upon them.

The work was carried on day and night; at night, the caissons upon which the masonry, etc., were progressing, were illuminated with two calcium lights, and a number of lamps. The air-chamber was lighted with candles and lamps, and part of the time with gasoline burners. Some trouble was experienced in the air-chamber from smoke, which was partially remedied by small ventilators leading to the outer air. On the whole, candles appeared to answer in the compressed air better than any of the lights tried.

After the caissons attained a depth below 50 feet, the workmen engaged in the air-chamber suffered more or less at times, after coming out of the chamber, from a species of muscular paralysis, and some who remained in too long, or were in some way unfitted to stand the pressure, died from the effects. Yet there were others engaged in the air-chambers from the beginning who worked till the very last, and who labored safely at one time under a pressure of nearly 50 lbs. to the square inch, at a depth of 110½ feet, working an hour at a time.

Dr. Jaminet, an experienced physician of St. Louis, paid particular attention to the effect of air-pressure upon the workmen, and was frequently in the air-chamber. He will probably prepare some views on the subject which may be valuable in connection with the working of hands in compressed air, etc.

XXII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in the following pages—

At a meeting of the Society, Dec. 20th, 1870.

## AN ACCOUNT OF THE REMOVAL OF SOME BROKEN PILES FROM THE BED OF THE CONNECTICUT RIVER.

A paper presented by J. ALBERT MONROE, Civil Engineer, Member of the Society.

During the winter of 1868–9, the clusters of piles driven for the "Cushing Piers" of the Connecticut River Bridge, at the Shore Line Railroad crossing, were left exposed and unprotected on account of the serving of an injunction which prevented the continuance of the work.

The up-stream cluster of Pier No. 2 had but four piles driven when the work was suspended. These stood in thirty-seven feet of water at low tide.

The freshet of the following spring brought down the river immense fields of thick ice, which formed a jam just above the site of the bridge.

When this gave away, it tore the platform from its place, carried away two of the four piles and broke off the other two. One was broken off just below the surface of the river bed, and the other about two feet below the first. When the work was resumed in the summer of '69, it was found necessary to remove these stumps or to change the location of the pier.

As the work on the superstructure was well advanced, it was determined to remove them.

Various methods were tried with poor success. The bed of the river is composed of a fine sand, which flowed back around the pile-heads as fast as a diver could remove it.

A curb of iron, eight feet in diameter, and three feet high, made of three eighth-inch boiler plate, was sent down for the diver to settle around the piles, so that the heads could be cleared, and a chain be passed around them, but progress was so slow, that method was abandoned and the following adopted, which proved perfectly successful.

A four inch gas-pipe five feet long, with a solid steel point, was placed beside the heads of the piles by the diver. Into this was inserted one end of an iron rod, long enough to reach from the bottom of the river to the reconstructed platform. On this rod was shrunk a heavy iron ring, just above the top of the gas-pipe, forming a shoulder for a hammer, sliding upon the rod, to strike upon.

By means of the hammer, which was raised by the pile-driver engine, the pipe was driven down until its top was within two or three inches of the surface of the river bed. When the tube was in place the rod was withdrawn and a charge of four pounds of powder, enclosed in a tin cylinder, inserted, which was covered with the river sand and exploded by means of a battery.

Both piles were thrown out by the explosion. One was uninjured ; the other was broken at about a right angle with the grain of the wood, the break extending to within about half an inch of one side.

The fracture was a perfectly clean one, none of the fibres of the wood pulling from one part to the other, and it was as clean as if the wood had been partially decayed.

These sticks were of yellow pine, twelve inches square and twelve feet long, and were driven the November preceding.

## XXIII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts or opinions advanced in any of its publications.

At a meeting of the Society, Jan. 4th, 1871.

## THE ANEROID BAROMETER AND ITS USE IN ESTIMATING ALTITUDES.

A paper presented by Gen. THEO. G. ELLIS, Civil Engineer, Member of the Society.

Entered according to Act of Congress in the year 1871, by THEO. G. ELLIS, in the office of the Librarian of Congress at Washington.

### THE ANEROID BAROMETER.

The invention of this useful little instrument is attributed to Conti about the year 1798; but it was revived and brought to nearly its present form by Dent and others about the year 1844, and has since that time been much used as a weather indicator both on sea and land.

During the past few years it has been much improved, and has become at the present day a much more useful and accurate instrument than heretofore, and one upon which we can rely for correct indications of the weight of the atmosphere with as great certainty as any except the best cistern mercurial barometers. The best aneroids, if properly used, far exceed in accuracy the ordinary mercurial barometers which have no

adjustable scale for contact with the mercury in the cistern, as will be hereafter described.

In its present form it becomes one of the most useful instruments in the possession of the engineer for the determination of heights with ease and rapidity in reconnaissances, owing to its extreme portability, and the few corrections and calculations required in reducing its observations. Even though it were far from being as accurate as it is, it would still be very valuable, as it can be carried by engineers when no one would think of transporting a mercurial barometer. In its pocket form it is as easily carried as a watch, and can be consulted whenever required; whereas the ordinary barometer must have a special attendant to transport it, and requires, at least, sufficient time to pack and unpack the instrument and set it up, in addition to the time necessary for observation.

The word aneroid is derived from the Greek privative ἀ, νηρος wet, and εἶδος form, and signifies a form without fluid, in contradistinction to the mercurial or fluid barometer. Instead of measuring the weight of the air by a column of mercury, it is determined by the pressure upon a vacuum chamber, measured by a delicate arrangement of levers and springs, which is, in fact, a sensitive balance for weighing the pressure of the atmosphere.

### CONSTRUCTION OF THE ANEROID.

The aneroid barometer consists essentially of a box or chamber from which nearly or quite all the air has been extracted, and which has its sides held apart by the action of a spring which balances the pressure of the atmosphere upon the outside of the chamber, and allows it to collapse or expand according as the pressure is greater or less. This small motion of the sides of the chamber is communicated by multiplying levers, and by a chain wound around the axis of the index, to the dial, where the amount of motion is sufficiently increased to be easily read upon the scale.

There have been many forms of metallic barometers made upon the above principle, and a great variety of modifications in the manner of transmitting the motion to the index.

The vacuum chamber has been made of annular form, with a section taken out upon one side, so that the space between should be altered by different pressures of the air.

The motion of the vacuum chamber has also been communicated to the index by a rack and pinion movement instead of the chain.

Although some of these last-mentioned instruments, especially the French ones, have been very nicely made, they possess errors inherent to the construction, which unfit them for anything but weather indicators, where great accuracy is not required. The only modes of construction that will be here described, or that are considered sufficiently accurate and reliable for measuring heights, are the so-called holosteric barometer, and the older form with the same vacuum chamber and index mechanism, but which has a lever and spiral spring for resisting the pressure of the air, in place of the large, flat spring of the holosteric form.

The first-mentioned is generally used for the large and medium-sized instruments, and the lever form for the smallest or watch size. This is on account of its being conveniently made much thinner or flatter for ease of carrying in the pocket. There is not much difference in accuracy between the two constructions when equally well made and properly used.

In the holosteric form of aneroid, the vacuum chamber consists of a cylindrical metallic box, of from two to three inches in diameter, and one-half inch in thickness, with corrugated top and bottom, from which nearly all the air has been pumped out, and the aperture soldered up air-tight. This chamber is firmly secured to the case by a screw which passes through the frame and enters a stud upon the middle of the lower surface of the chamber. Above the chamber is a wide flat ⊃ spring, the lower half of which rests upon two standards, on opposite sides of, and in line with, the centre of the vacuum chamber, and just outside of its circumference. A central stud, upon the upper surface of the chamber, passes through the upper leaf of the spring, and is secured by a triangular knife-edged pin passing through it in exactly the direction of the standards before mentioned.

On the side next to one of the standards, an arm extends forward from the under leaf of the spring, and is attached to the frame by an adjustable screw, so that the spring has three points of support at the bottom, and by means of the last-mentioned screw can be slightly tipped forward or backward, as may be desired for the purpose of adjustment.

From the upper leaf of the spring an arm extends forward, at right angles to its supports, and is firmly attached to the spring, so that its

farther extremity describes an arc as the spring opens or shuts from the decrease or increase of pressure on the vacuum chamber. It is in this bar that the compensation for temperature of the instrument is made.

Beneath the end of this arm is a short horizontal spindle, with a short horizontal arm lying in the same direction as the compensation arm, and to which it is connected by a link; it also has a longer vertical arm to which one end of the chain is attached. The short arm is furnished with a screw for shortening or lengthening it, to increase or diminish the range of the index, and it sometimes has another adjustment for turning it around the axis relatively to the other arm, in order to vary the rate of movement of the index in different parts of the scale. The chain passes from the end of the vertical arm of the lever around the axis of the index.

In the other construction mentioned above, as generally used for pocket aneroids, in place of the flat ⊃ spring over the vacuum chamber there is an F-shaped lever, the back of which rests on two knife edges rising from the bottom of the frame and forming the fulcrum. The centre stud of the vacuum chamber is attached to the short middle arm by means of a knife-edged pin, and the long arm rests on the top of a spiral spring, which has an adjusting screw under the small circular bottom plate on which it rests, for the purpose of regulating its height. The compensated arm runs parallel to this arm of the lever, just inside of it, between it and the short middle arm. In uncompensated instruments the arm of the lever is often used directly for transmitting the motion to the dial.

The mechanism connecting the compensated arm with the index is the same as before described. Both of these instruments have a means of adjusting the short arm of the lever upon the horizontal spindle, so that the index will move as uniformly as possible through all parts of the dial scale.

The instrument is compensated for differences of temperature, so that the index shall remain at the same reading upon the dial when it is heated and cooled. This is done by filing out a portion of the arm before described along its upper side, and inserting a strip of steel, which is carefully soldered in its place. The arm being usually of brass, the difference in the rate of expansion of the two metals causes it to bend in such a way as to counterbalance the effect of changes of temperature on the other parts of the instrument. The length of the steel bar necessary

to compensate the aneroid is found by trial. A number are usually heated and cooled together. Some are found to be nearly or quite correct for temperature, while others require a steel bar almost the whole length of the arm. This is occasioned by the different amounts of air remaining in the vacuum chamber. A certain quantity is found to almost perfectly compensate the instrument, but it is impossible to regulate this amount with sufficient nicety to dispense with the compensation of the arm.

After compensation the dial is marked by trial, so as to agree with the mercurial column at the principal divisions, and is divided proportionally between. A small final adjustment, by means of the interior adjusting screws, is made if the scale does not exactly correspond to the height of the mercury when the instrument is finished. These final adjustments should always be made so that the scale of the aneroid will conform to the height of the mercury at a certain temperature, preferably at 32° Fahr., as that is the temperature to which all barometrical observations are generally reduced, and for which all tables are constructed. It is believed, however, that this is rarely if ever attended to by the makers.

Sometimes the scale is divided uniformly, which it must be if it has a vernier attached, in which case the movement of the index is made to conform as nearly as possible to the scale by means of the interior adjusting screws. The scale errors must be noted.

In many aneroids, and generally in the best of the smaller ones, there is an additional scale of altitudes in feet, outside of the scale corresponding to inches of mercury. This usually commences with 0, at 31 inches, and is generally divided and figured, in the best English instruments, according to the table prepared by Professor Airey, which will be mentioned hereafter. There are some, however, very erroneously marked.

In the largest and most accurate instruments this extra scale is scarcely desirable, as the formula upon which it is divided may not, perhaps, be the best, and the divisions of inches and hundredths are in some degree confused by it. The corrections of the scale, also, which are mentioned hereafter, and are sometimes necessary to correct observations, are usually made for the inch scale, and are not applicable to the geometrically varying scale of feet. In the smaller aneroids, however, when graduated with a correct formula, it is a great convenience for giving approximate heights without the difficulty of carrying tables or making calculations, except

the necessary correction for the temperature of the air. It is, in fact, a table of itself.

Sometimes the scale of feet is made movable, with a zero point either at 31 or 30 inches. This is done with a view to placing the zero opposite the index at the lower one of two stations, of which the difference of level is required, and reading off the height directly from the scale at the other, instead of taking the difference of the readings, as is required with a fixed scale. This movable construction is entirely erroneous, as there is but one position in which it can be correct, as will be seen in what follows when considering the manner of estimating heights.

In place of the pointer attached to the centre of the glass, usually found in the poorer class of aneroids, the best now have a small pointer attached to the rim which carries the glass, and reaching out to meet the end of the index, opposite to which it can be accurately placed. When there is a vernier it is likewise attached to this rim, which is made to turn freely and evenly, but with sufficient friction to hold it in any desired position.

At the back of the case there is generally observed a small hole, with a screw head just within the case. This screw is under the third support of the spring in the holosteric form, as before described, and in the other mode of construction is under the spiral spring which supports the long arm of the vacuum-chamber lever. The object of this screw is to move the position of the index on the dial and set it at a reading to agree with the height of the mercurial column. This is done by raising or lowering the spring which sustains the pressure of the atmosphere on the vacuum chamber. It should never be touched except to replace the index to agree with the mercury, in case it should become deranged, and this, if necessary, should be done before the trial to test the final adjustment of the instrument.

Mr. James Pitkin, of London, has made a great improvement in this adjustment by constructing the case so that the mechanism is attached to the bottom and the dial to the body, and arranging them to turn upon each other when necessary and be fastened by a set screw. This moves the dial to any position under the index; it corrects the reading without altering or affecting the mechanism in any way, and does not alter the range of the index upon the scale. As yet this contrivance has been

applied only to pocket aneroids, but would be valuable on the large sized ones, although the holosteric form is not generally so much disturbed by moving the ordinary adjusting screw as that adopted for the smaller sizes.

All aneroids should have an attached thermometer, unless they are perfectly compensated, which is rarely the case. For scientific purposes the central part of the dial should be sunk to a sufficient depth, and the thermometer placed below the index, so that it can traverse above, close to the divisions of the scale, to avoid parallax.

The aneroid barometer, as at present constructed by the best makers, is an instrument of great sensibility and accuracy, and, if properly used, is capable of determining heights with quite as great accuracy as the mercurial barometer. The disfavor which it has met with in the hands of some observers has been from a want of knowledge of its construction, and from the use of cheap and poor instruments. For engineers, and other scientific purposes, fully nine-tenths of the aneroids sold in the shops are absolutely worthless. They have a large index error for temperature on account of not being compensated, and are so badly made that the index moves unsteadily and by jerks along the scale. With the cheaper sort of instruments the scale is divided uniformly, and the movement of the index is adjusted to it, as nearly as may be, afterwards. A good aneroid should always have its dial divided by trial after the working parts are completed, and the index should move evenly and uniformly over the scale during a change of pressure. The error of compensation for temperature should never exceed one-hundredth of an inch in each 10° Fahr. With a pocket barometer it may be more without material error, if carried in an inside pocket where the temperature is nearly uniform.

### TESTS AND ADJUSTMENTS OF THE ANEROID.

On purchasing an aneroid, a table of its index errors should, if possible, be obtained from the maker; but this is seldom or never obtained when they are bought in the shops. They are made to be as nearly correct as possible; but for scientific purposes their errors, if any, must be known. Before using the aneroid for accurate observations, it should be carefully tested under an air-pump together with a mercurial column, at a known

temperature, and its scale errors, if any, carefully noted while the air is being pumped out. This should be done slowly, so as to occupy at least five minutes to each inch of the scale. This is necessary to allow the parts time to adjust themselves to the new position. On reaching the end of the scale it is best to let the same pressure remain for ten or fifteen minutes, to ascertain if the index will continue to fall. If it does, it must be allowed sufficient time to come to rest, and the error must be divided proportionally over the whole scale in noting the errors.

This comparison is always made too rapidly by the makers, so that most aneroids read too low at high altitudes.

On readmitting the air again to the receiver of the air-pump, if the index is allowed to rise rapidly, it will not return at once to the position it started from into about one-hundredth for each inch it has been pumped down, but requires about ten minutes to each inch to recover itself. If this time is taken in letting in the air it will generally move entirely back to its original position. This is not a sluggishness of the index, as the aneroid shows slight changes more quickly than the mercury, but is probably occasioned by a slight set in the metal of the vacuum chamber, or a change of the position of the knife-edges of the lever. It occasions no error or uncertainty, however, in using the instrument, as there are no circumstances in actual practice, unless it be mounting rapidly in a balloon, where the changes of level could be made so quickly as to occasion the least inaccuracy from this cause, and even then it would be of no possible consequence.

The aneroid barometer should be uniformly adjusted by the makers to read inches of mercury at the level of the sea, in 45° of latitude, and at a temperature of 32° Fahrenheit, as that is what is usually understood by "inches of mercury."

The first two corrections are immaterial at altitudes of less than 5,000 feet, and between latitudes 40° and 50°, for all ordinary comparisons of aneroids with the mercurial column; but the last is quite important unless the comparison is made at near 32° Fahr.

The small tables I., II., and III., are given to show the amount of these errors. They will also be found useful for comparing observations taken in the field with the mercurial and aneroid barometers, as they contain all that is absolutely necessary for reducing the mercurial observations.

After ascertaining the index errors as above, the instrument should be gradually heated and cooled through a range of temperature as great as that it will be subjected to in practice, and the amount of movement of the index for each 10° carefully noted. This will be generally quite uniform for different positions of the index and different degrees of heat, so that a correction of a certain amount for each 10° of change will be sufficiently accurate. If this error is large, even to the amount of three or four hundredths in 10° Fahr., accurate observations may be taken by giving the instrument time to acquire a uniform temperature before reading and making the proper correction. After a careful trial of corrections as above, a good aneroid will remain a long time in adjustment, probably several years, if it does not receive some injury from a fall or blow. If it has an attached thermometer, any blow that does not break that, will not probably damage the adjustments. It is well, however, to test it whenever there is any doubt of its accuracy. A small pocket aneroid of two inches diameter, which the writer now has in his possession, made by James Pitkin, of London, was carefully tested under the air-pump in August 1869, with the following readings :

| MERCURY. | ANEROID. | DIFF. |
|---|---|---|
| 30.00 | 30.00 | 00 |
| 29.00 | 29.00 | .00 |
| 28.00 | 27.99 | −.01 |
| 27.00 | 27.00 | .00 |
| 26.00 | 26.01 | + 01 |
| 25.00 | 25.00 | .00 |
| 24.00 | 23.99 | −.01 |
| 23.00 | 22.97 | −.03 |
| 22.00 | 21.96 | −.04 |
| 21.00 | 20.94 | −.06 |

It was subsequently carried on several journeys, and over the mountains of Switzerland, with no extraordinary care, and was again tested with the same apparatus as before, in May, 1870, with results as follows :

| MERCURY. | ANEROID. | DIFF. | ERROR. |
|---|---|---|---|
| 30.00 | 30.00 | .00 | .00 |
| 29.00 | 29.00 | .00 | .00 |
| 28.00 | 28.00 | .00 | +.01 |
| 27.00 | 27.00 | .00 | .00 |
| 26.00 | 26.02 | +.02 | +.01 |
| 25.00 | 24 99 | -.01 | -.01 |
| 24.00 | 23.99 | -.01 | .00 |
| 23.00 | 22.97 | -.03 | .00 |
| 22.00 | 21.98 | -.02 | +.02 |
| 21.00 | 20.94 | -.06 | .00 |

The first comparison was not at hand when the second was made.

Considering the smallness of the dial and consequent errors of observation in reading, the two comparisons are very close together, and show the reliability of a good aneroid. The error, or difference between the two readings of the aneroid, was in three places only .01, and in one place .02, the rest being the same, as shown in the fourth column above. These are more likely to be errors of reading than any change in the instrument. The temperature error of this barometer is about $\pm$ .01 for each 10° Fahr. It is evident that even with this small pocket aneroid, if a proper formula be applied to its readings, its indications of differences in level must be nearly or quite as accurate as those of a mercurial barometer. After an aneroid is tested, as above described, the screw at the back for adjusting the position of the index to agree with the mercury *must not be touched*, as it alters the relations of the working parts and disturbs the observed corrections to be applied to the scale.

If the instrument is a new one, the index will generally rise as much as a tenth of an inch above where it was set, when compared with the mercury, before coming to its proper bearing; but this will not affect the relative accuracy of the readings. If it is desired to know the height of the mercury at any time, a constant known error is to be subtracted from the reading of the aneroid; but it is immaterial so far as differences of readings for ascertaining altitudes are concerned.

With the improved construction of Mr. Pitkin, before mentioned, where the dial only is moved, the index can be set with the mercury at any time without disturbing the adjustment.

### THE MERCURIAL BAROMETER.

As the height of the mercurial column is made the standard for aneroids, and to which they must be adjusted at some standard temperature, it becomes necessary to understand, in some measure, the construction and use of the mercurial barometer, and to have a knowledge of its necessary corrections and sources of error, to make our comparisons more intelligently.

There are two principal varieties of mercurial barometer used for scientific purposes, viz.: the cistern barometer and the siphon barometer.

The first is undoubtedly the best and most accurate instrument. It consists of a straight glass tube of about one-fourth of an inch diameter, secured generally by leather packing into a cistern of glass and wood held together with metal fastenings. The tube extends nearly to the bottom of the cistern, so that the lower end shall come below the surface of the mercury. The scale for measuring the height of the mercury in the tube is usually of brass, and made movable, to adjust for capillarity of the tube. The cistern is fitted with a point attached to its top and forming the zero of the scale, which can be made to just touch the mercury in the cistern by means of a screw at the bottom of the case. The scale measures the exact height of the column when the point is brought into coincidence with the surface of the mercury in the cistern. The point is sometimes attached to the brass scale and moves with it.

Some barometers of this form are made with a fixed scale, and without any means for adjusting the height of mercury in the cistern. Such instruments are of no use except as weather glasses.

The siphon barometer has the mercurial tube in the form of an inverted siphon, the shorter arm of which is open to admit the air. It has usually a brass scale for reading the height of the two columns, whose difference indicates the true weight of the atmosphere.

This barometer is lighter and more portable than the first, but is less accurate and reliable.

The maximum errors of the cistern barometer, when compared directly with a standard, were found by Major Williamson, of the United States

Engineers, within the range of from 29″.657 to 30″.303, in three different instruments to be, respectively, .008, .007, and .007. The maximum errors of the siphon barometer compared with a standard were found by the same authority in three cases to be .047, .062, and .068, in a range of from 29″.871 to 30″.340. The cistern barometer, it will be seen, is by far the most accurate instrument, and good aneroids should be compared with no others.

Mercurial barometers are necessarily handled with great care, to prevent fracture or the introduction of air bubbles into the tube. In transporting them, even across a room, the cistern should be screwed up and the instrument carried in an inverted position. A very slight jar will often introduce an air-bubble into the tube, when it becomes worthless for correct observations until it is repaired. The barometer must be taken to pieces, and the mercury re-boiled in the tube by an experienced person, before it becomes again fit for use. This requires the transportation of a variety of implements and apparatus in addition to the barometer itself. For these reasons many observers have preferred the siphon variety, with all its inaccuracy, as being less liable to accident in transportation.

The corrections usually applied to the readings of the mercurial barometer in estimating heights are as follows:

1. Reduction to 32° Fahr., or to some uniform temperature for different observations, to correct the height for the expansion of the mercury. This correction is dependent upon the expansion in length of the scale, as well as the expansion in bulk of the mercury.

2. Correction for the difference in the force of gravity acting upon the mercury in different latitudes.

3. Correction for decrease in the force of gravity acting on the mercury when carried above the sea level.

4. Correction for the decreased force of gravity acting upon the air at different heights, by which its density is diminished.

5. Correction for the temperature of the air above or below a certain standard.

6. Correction for the different densities of the air occasioned by humidity.

7. Correction for capillarity of the tube.

The first correction is a very important one for the mercurial barometer,

but becomes nothing in the aneroid, which is compensated for temperature. If not so corrected, the errors must be found by experiment, and applied to the observed readings, to reduce them to a certain standard.

The second correction is also an important one for the mercurial barometer, but is nothing in the aneroid.

The third correction must likewise be applied to all observations with the mercury, although not affecting the aneroid.

If it is wished to compare the readings of an aneroid with the mercury, the above three corrections must be applied to the readings of the mercurial barometer to reduce them to equal heights.

If readings of the mercurial barometer, reduced to 32° Fahr., are given in any experiments for ascertaining heights, and we wish to find the true reading for the same stations of an aneroid, which represents inches of mercury at 32° Fahr., at the sea level, in 45° latitude, we must apply the second and third corrections to the mercurial reading.

The second correction, however, for a height of 10,000 feet, and for latitudes from 35° to 55°, is less than 9 feet. For a less height, and for latitudes nearer to 45°, it is proportionally less. At 45° latitude it is zero. Thus it will be seen that this correction can generally be disregarded, being extremely small for ordinary observations. The third correction, for a difference of height of 10,000 feet, is about 30 feet, and becomes important in comparing readings as above. It is nearly proportional to the height for less altitudes.

The fourth correction applies to the aneroid as well as to the mercurial barometer. Its amount, however, is extremely small. For a difference of altitude of 10,000 feet, and the height of the barometer at the lower station 25 inches, the correction is only 4.5 feet. With less difference of altitudes and higher barometer at the lower station, it may be wholly disregarded.

The fifth correction is equally applicable to all barometrical estimations of differences of altitude, and will be considered further on.

The sixth correction is also applicable to all barometrical observations for heights, but its amount is so uncertain, even with the best observations for humidity of the atmosphere, that many of the best formulæ do not embrace it in the calculation of altitudes. It is usual to give a slightly greater value to the correction for temperature of the air to compensate for the humidity. It is perhaps better, however, with great differences of

altitudes, and when great accuracy is desired, to take observations of the humidity of the air, and make the correction. Its amount is, however, unimportant in ordinary observations.

The seventh correction is usually made on the scale, and is different for every tube. Whenever a new tube is put into a barometer, a direct comparison must be made with a standard barometer to ascertain the amount of this error. It is considered constant, and the scale is generally moved to make the correction. A line is drawn on the frame of the instrument exactly 30 inches from the point in the cistern, and the 30-inch division of the scale is moved away from it, the amount of the error. This correction is, however, not constant for more than a few inches of the scale. It diminishes in amount in the lower readings of the mercury, and there should be a tabular correction for each inch if its amount were known.

This, and the first-mentioned correction for temperature, are usually applied to the readings; the others are generally embraced in the formula for estimating heights.

### CORRECTIONS TO BE APPLIED TO OBSERVATIONS WITH THE ANEROID.

1. If the instrument is not perfectly compensated for temperature, the correction previously observed must be added or substracted to reduce the readings to 32° Fahr., or some standard temperature.

2. Correction for the decreased force of gravity, acting upon the air at different heights, by which its density is diminished.

3. Correction for the temperature of the air above or below a certain standard.

4 Correction for the different densities of the air, occasioned by humidity.

The above are the corrections of the aneroid to obtain the same results as with the mercurial barometer, and they are given to show what corrections might be made in very accurate experiments on high altitudes.

The third correction is the only one that is usually necessary in estimating heights, and that is always embraced in the formula.

The others, as we have already seen when speaking of the mercurial barometer, are immaterial in ordinary observations. If great accuracy be desired, the amounts of the above corrections can be taken from the tables of Guyot or Williamson, and even then it is exceedingly doubtful whether

the results are much nearer the truth for introducing them. All of the more important corrections are eliminated from the aneroid by its construction and adjustment.

### VARIATIONS IN THE HEIGHT OF THE BAROMETER.

The variation in the height of the mercurial column is occasioned by the difference of weight of the vertical column of air above the instrument. The atmosphere is subjected to various forces and disturbing causes, about which very little is known, producing fluctuations of greater or less extent in different portions of the globe. The principal periodical changes in the weight of the atmosphere are two: First, a gradual change, generally extending over a period of two or three days, and causing the barometer to rise or fall gradually during that time. These changes are, however, sometimes more or less sudden, and may occupy but a few hours. They follow no known laws, and appear to be occasioned by great waves in the atmosphere, resembling the tides in the ocean, but occurring without regular intervals. Second, a regular horary pulsation occurring at about the same hours every day, and having a magnitude entirely independent of the diurnal variation of the larger waves above mentioned. There are also changes in the weight of the atmosphere resulting from changes of temperature, and from the different amount of humidity contained in it at different times.

The first change of height mentioned, or that which occurs from day to day, is by far the greatest, and is the only one generally noted for foretelling the weather. It usually extends over large tracts of country, and in settled weather the barometer rises and falls quite gradually and uniformly. It is owing to the extent of these great waves, and their slowness and uniformity of motion, that we are enabled to use the barometer as a levelling instrument.

The change during the day, or, as it is usually called, the horary variation, is a disturbance of the weight of the atmosphere, the cause of which is not well known. It is probably caused by the action of the sun in heating the air. This is the more probable, as the greatest fluctuation occurs during the day while the atmosphere is becoming heated.

There are two maximum and two minimum points during the twenty-four hours. The averages for the year are about as follows:

First maximum.....at about 9 A. M.
First minimum.....at about 4 P. M.
Second maximum.....at about 11 P. M.
Second minimum.....at about 3 A. M.

The maximum and minimum points for each fluctuation are at about equal distances above and below the average of a uniform rise or fall. The day fluctuation is the larger, that during the night being usually less than one-half of the amplitude of the preceding wave.

The times of the maximum and minimum points vary with the season. In midsummer they are as follows:

First maximum..... 8 A. M.
First minimum.....5.30 P. M.
Second maximum..... 12 MIDNIGHT.
Second minimum..... 2 A. M.

In midwinter they are as follows:

First maximum..... 10 A. M.
First minimum.....2.30 P. M.
Second maximum..... 10 P. M.
Second minimum..... 4 A. M.

The times of these changes do not recur with any great regularity, and averages of hourly observations for many days are necessary to determine them. Their amplitude varies with the latitude; being greatest near the equator, and diminishing toward the poles. The amounts are not equal at all places of the same latitude, and a series of experiments is necessary to determine them at any place with exactness.

The average amounts of the greatest, or day variation, above or below the average for different latitudes at the sea level, are as follows:

| LAT. | IN. |
|---|---|
| 0 ° | .091 |
| 10 ° | .088 |
| 20 ° | .078 |
| 30 ° | .062 |
| 40 ° | .043 |
| 50 ° | .023 |
| 60 ° | .004 |
| 62½° | .000 |

The average amplitude at Girard College, Philadelphia, in lat. 40°, is .034. These quantities diminish as we go upward, but the law is not known. At 10,000 feet they are about one-fourth of the above.

With regard to the temperature of the atmosphere, there seems to be no general law. It has been supposed by some that there was a decrease of temperature of 3° Fahr. for each 1,000 feet of altitude; but more recent experiments show that the decrease is more rapid near the earth than at a great height. Sometimes, however, it has been found that the same temperature extended to a height of many thousand feet. It is extremely probable that, although there is a general decrease of temperature as we ascend, yet every current of air that we pass through has its own temperature, acquired in hotter or colder regions, and may vary materially from the air above and below it.

The humidity of the air is also a very uncertain element. The theories regarding its influence upon the weight of the atmosphere are very imperfect, and do not seem to always bear the test of experiment. It is generally supposed that the vapor in the atmosphere follows the law of a gas mixed with the air, and, according to the usual law of gases, is densest near the surface of the earth. Maj. Williamson has, however, observed at Monte Diablo, in California, a greater amount of vapor in the air at a height of nearly 4,000 feet above the level of the sea than at that level, and this for many days in succession. This would be impossible if the vapor followed the supposed law.

Is it not more reasonable to presume that various currents of air are charged with different amounts of humidity, and that it remains suspended until an over-saturation or change of temperature causes a deposition of visible moisture in the form of dew or rain?

### FORMULÆ FOR COMPUTING HEIGHTS.

There are several different formulæ for computing heights by the mercurial barometer, derived from different authorities and different data, all of which have their advocates and are more or less used by the best observers. The results are sufficiently uniform, however, and agree so nearly with actual heights obtained with the spirit level, where a comparison has been made, as to demonstrate that they are sufficiently accurate to warrant confidence in their use. It is probable that in some cases one formula will give more exact results, and in other cases another will

prove better. For this reason the different authorities are given and an attempt made to select that which will generally give the best results.

The formula given by Guyot in his valuable collection of tables published by the Smithsonian Institute, and which is based upon the formula of La Place, both for pressure and temperature, derived from the experiments of Biot and Arago and the trigonometrical surveys of Ramond, is as follows :

$$(A.)\ D = \frac{H}{\log h\,[1 + .00008967\,(T - t')]} \times 60158.6 \left\{ \begin{array}{c} 1 + \dfrac{T + t - 64}{900} \\ 1 + .0026 \cos 2\,L \\ 1 + \dfrac{d + 52252}{20,886,860} + \dfrac{H}{10,443,430} \end{array} \right.$$

$D$ = difference of height in feet.
$d$ = approximate difference of height calculated by first term.
$H$ = height of barometer at lower station.
$h$ = " " " upper station.
$T$ = temperature of air at lower station.
$t$ = " " " upper station.
$T'$ = " " barometer at lower station.
$t'$ = " " " " upper station.
$L$ = mean latitude of two stations.

The first term is intended to give the approximate height in feet at the temperature of 32° Fahr.

The second is the correction for the temperature of the air.

The third is a correction for gravity at the given latitude.

The fourth contains the two corrections due to a decrease of gravity acting on the mercurial column, and a decrease of gravity acting on the air. The last term is as given by Guyot, although the numerator of the last fraction evidently should be the approximate height in feet of the lower station in place of $H$.

This formula, it will be observed, has no term for vapor correction; the effect of moisture in the air being included in the correction for temperature of the air.

Plantamour's formula, which is based upon the more recent experiments of Regnault, is given by him in the following form:

$$D = \log \frac{H}{h}\, V \frac{1}{1 - W \frac{a + a'}{V\ H\ h}} \times g$$

$V$ is the coefficient.
$W$ is a factor depending on the temperature of the air.
$a$ and $a'$ the observed humidity at the two stations.
$g$ a factor depending on the latitude.
$D$, $H$, and $h$ as before.

Reducing the French measures to feet and giving the same form to this formula as the preceding, we have,

$$\text{(B.)} \qquad D = \log \frac{H}{h} \times 60384.3 \begin{cases} 1 + \dfrac{T + t - 64}{982.2647} \\ 1 + .0026257 \cos 2\ L. \\ 1 + M \end{cases}$$

$M =$ correction depending upon the humidity of the atmosphere. This is to be used in connection with the given temperature correction, which will not give accurate results without it. $H$ and $h$ are supposed to be reduced to 32° Fahr.

The term for decrease of gravity in altitude that appears in La Place's formula is comprised in the constant in the first term of Plantamour's.

Professor Rankine's formula, as given in his Civil Engineering, p. 92, with the correction given in his addendum, p. 783, is :

$$\text{(C.)}\ D = 60360\ [\log H - \log h - .000044\ (T' - t')] \begin{cases} 1 + \dfrac{T + t - 64}{986} \\ 1 + .00284 \cos 2\ L + \dfrac{h'}{10450000} \end{cases}$$

$h' =$ mean of heights in feet above the sea level.

The term for a decrease of gravity in altitude, acting on the mercurial column, is wanting in this formula, and is probably intended to be included in the constant in the first term. The height of the mercury at the upper station is reduced to correspond with the temperature at the lower by means of the term containing $T' - t'$.

The table recently prepared by Professor Airey, the British Astronomer Royal, before referred to as being generally used in graduating the foot scale upon aneroids, is given by him as correct at 50° Fahr., or 10° Centigrade, with a temperature correction of $\pm \frac{1}{1000}$ part of $D$ for each degree Fahr. above or below $T + t - 100$ Fahr., or $\pm \frac{1}{555}$ part of $D$ for each degree Centigrade above or below $T + t - 20$ Centigrade.

These corrections are not exactly equal. It is somewhat doubtful whether it is intended that the aneroid shall be adjusted to read inches of mercury at 50° Fahr., or inches of mercury at 32° Fahr., the standard to which all mercurial observations are generally reduced, and for which tables are ordinarily constructed. The difference, however, is not material, and in the absence of the formula from which the table was prepared, it

is reduced to a formula of the usual form at 32° Fahr. for the purpose of comparison.

This is as follows:

(D.) $$D = 60500 \log \frac{H}{h}\left(1+\frac{T+t-64}{964}\right)$$

This formula will produce all the quantities of Airey's table, used with his correction for temperature of the air, for all heights of the barometer and all temperatures.

Baily's barometric formula, given in his Astronomical Tables and Formulæ, is as follows, using the same notation as before in place of his:

$$D = 60345.51\left[1+.001111\,(T+t-64)\right] \times \log\left[\frac{H}{h}\times\frac{1}{1+.0001\,(T'-t')}\right] \times [1+.002695\cos 2\,\mathrm{L}].$$

Putting this in the same form as the preceding formulæ, we have,

(E.) $$D = 60345.51 \log\left[\frac{H}{h}\times\frac{1}{1+.0001)(T'-t')}\right]\left\{1+\frac{T+t-64}{900}\right\}_{1+.002695\cos 2\,L}$$

The quantity in the first term by which $\frac{H}{h}$ is multiplied is the correction for reducing the observed height of the upper station to the temperature of the lower. The other corrections are the same as have been heretofore explained.

The coefficient of the first term is the same as that of La Place with the correction for decrease of gravity in altitude added.

This formula has been used on the United States Coast Survey in preference to others.

There is a very good barometrical formula with accompanying tables, which gives the same result as Baily's formula. It is as follows:

Make $R = \log H - B \log h$.

Then logarithmic difference of altitude in feet, or $\log D, = A + C + \log R$.

$A$ is a tabular logarithmic number depending upon the sum of the detached thermometers, or $T+t$.

$B$ is a tabular logarithm depending upon the difference of the attached thermometers, or $T'-t'$.

$C$ is a tabular logarithm depending upon the latitude.

The constant for the pressure of the air at 32° and the correction for temperature are evidently both included in $A$.

To reduce this formula to the same form as the preceding ones, we take the value of $A$ at 32° from the tables and find the corresponding number to be 60,346. We then take the value of $A$ for other temperatures, as high as the tables extend, and find the increase to be uniformly $\pm \frac{1}{900}$ for each 1° of the sum of the temperatures.

As the sum of the logarithms in the second member of the equation is equal to log $D$, we have, calling $C_n$ the number corresponding to $C$ and substituting the known quantities before found:

$$\text{(F.)} \qquad D = 60346 \times (\log H - B \log h) \times C_n \times \left(1 + \frac{T + t - 64}{900}\right)$$

which is of the same general form as those which have been previously considered.

There have been many other rules given for obtaining approximate heights with the barometer, but none of sufficient accuracy or importance to merit attention. It is sometimes convenient, however, to have a formula that can be used without any tables whatever. Such a one can be derived from a rule proposed by Sir George Shuckburg. This gives the formula:

$$D = \frac{30\, a\, b}{A}$$

$A$ = mean height of barometers in inches.
$a$ = difference " " " "
$b$ = a tabular number corresponding to the mean detached thermometers.

This can be put into a convenient form as follows:

$$D = \frac{30\, a\, b}{A} = \frac{30\, b\, (H-h)}{\frac{1}{2}(H+h)} = 60\, b\, \frac{H-h}{H+h}$$

in the table $b = 917.2$ at 55° Fahr., substituting, we have

$$\text{(G.)} \qquad D = 55032 \frac{H-h}{H+h}.$$

Taking other temperatures we find the correction for temperature to be $\pm \frac{1}{435}$ of above for each 1° Fahr. above or below a mean temperature of 55°.

As the aneroid barometer is not affected in its readings by the variation in the force of gravity, it needs no correction for the latitude, nor for the decrease of gravity in altitude acting on the mercurial column.

The correction for the decrease of gravity in altitude acting on the density of the air, and the correction for humidity, remain; but the first is so small in amount, and the second is so uncertain, even when observations for its value are taken, that it is perhaps better to leave the first out altogether, and combine the second with the correction for temperature, as is done in all the preceding formulæ except that of Plantamour.

For the averages of long-continued observations for scientific purposes, these quantities can be included, but it is exceedingly doubtful if they add to the accuracy of the result, even when the mercurial barometer is used.

Tables for these values will be found in Guyot, and in Major Williamson's collection, before referred to.

For all ordinary observations for differences of heights the corrections above named are too small to affect the result, and the uncertainty of the vapor correction is sometimes the cause of error when introduced, and the greater accuracy is only apparent.

The preceding formulæ reduced to a form suitable for the aneroid, by leaving out unnecessary corrections, become as follows:

La Place's formula becomes,

$$(A'.) \qquad D = 66159\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{900}\right)$$

Plantamour's formula has a term $M$ for humidity to be added, which, if left out, would make the temperature correction too small. The temperature term of La Place is therefore substituted for it, as being the equivalent of the two corrections of Plantamour.

It then becomes,

$$(B'.) \qquad D = 60384\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{900}\right)$$

If it is desired to use this formula with the vapor corrections, extensive tables are required like those of Guyot or Williamson.

Rankine's formula becomes,

$$(C'.) \qquad D = 60360\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{986}\right)$$

Airey's formula becomes,

$$(D'.) \qquad D = 60500\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{964}\right)$$

Baily's formula becomes,

$$(E'.) \qquad D = 60346\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{900}\right)$$

Formula F becomes,

(F'.) $$D = 60346\ (\log H - \log h) \times \left(1 + \frac{T + t - 64}{900}\right)$$

or exactly the same as Baily's.

In formulæ E' and F' the coefficient of the first term contains the correction for decrease of gravity in altitude, which does not affect the aneroid, so that theoretically they should be reduced to the same quantity as in La Place's formula. The same amount is also included in the coefficient of Plantamour's formula B'. Formula C' contains the correction for decrease of gravity acting on the mercury only, and the coefficient should be reduced by about 180. As, however, these coefficients are all probably too small, they have been allowed to remain as they are. Major Williamson takes the coefficient of Plantamour's formula as here given, and again adds the correction for altitude without inaccurate results.

In the rule deduced from Sir George Shuckburg's formula, the correction for temperature of the air is too large. For the approximate formula, which can only be used up to about 3,000 feet of altitude, no material variation will be made by dropping the 32 feet in the constant, and calling the correction for temperature $\frac{1}{500}$; we shall then have,

(G'.) $$D = 55000\frac{H-h}{H+h} \pm \frac{1}{500}$$

for each degree of mean temperature above or below 55° Fahr., a formula very easily remembered, but useful only when no table of logarithms is at hand.

Upon examining the first six of these formulæ we notice some differences in the values of the constants for the pressure term, and also for the correction for the temperature of the air. The seeming differences are, however, quite small when compared with each other, and are within the amount of discrepancies produced by natural causes of error in the observations usually taken for the estimation of heights. Thus, in the formulæ B' C' E' and F', the constants for pressure in the first term would be within the difference produced by an error of 1° Fahr. in the estimation of the mean temperature. The constants have been mainly derived from experiments upon the weight of air and mercury, and their relative expansion at different temperatures, and will in time be modified by continued observations upon actual heights measured with the levelling instrument. From long continued and accurate observations at several places, it is

apparent that the constants are too small—all the formulæ giving too great a height in summer and too small in winter; but the data are yet too few to warrant a change. The sources of error arising from the humidity of the air, and the difficulty of getting the exact mean temperature of the air, are far greater than those of the formulæ. Long series of careful observations are necessary to obtain the exact average difference of the barometer and thermometer at any two stations, and all the data must be known with the greatest precision, and be compared with others at different localities, in order to much improve our present formulæ.

From long continued and careful observations taken at Geneva and the Great St. Bernard, as well as from observations taken in the United States, it is presumed that the coefficient of the pressure term and the denominator of the temperature term should be increased; but the apparent discrepancies may arise from other causes. It is supposed that Prof. Airey, in his table, has increased the constants for this reason.

Among the several formulæ presented, the one which seems to have the greatest weight of opinion in its favor is that of Plantamour. The best tables we have for facilitating computations of heights are based upon it, and at the present time it is, for mercurial barometers, the best in use. The corrections for temperature and humidity are both embraced in it, so that for continued and accurate observations it enables us to arrive at more accurate results than any other formula. These quantities are, however, of difficult computation, and are generally taken from tables. For single observations it will be equally accurate to take the correction for temperature and humidity combined, as given by La Place. We then have the formula:

$$D = 60384\,(\log H - \log h) \times \left(1 + \frac{T + t - 64}{900}\right)$$

This can, however, be put into a more convenient form for computation without tables, such as Williamson's etc. The second or temperature term, it will be observed, is always a proportional part of the constant in the first term; we, therefore, compute the number of degrees of temperature the standard of the first term must be changed to make the constant some easy multiplier, say 60,000. Now, $\frac{1}{900}$ of $60384 = 67.09$; to diminish the constant, therefore, by 384 we must lower the standard temperature $\frac{1}{2}$ of $\frac{384}{67.09} = 2°.86$, or nearly 3° Fahr.

We therefore have our standard for a constant of 60,000 at 29° Fahr.

The correction for temperature now becomes a certain proportional part of 60,000 instead of 60,384. $\frac{67.09}{60000} = \frac{1}{894}$ nearly. As taking the average of temperature correction of the several different formulæ would bring the denominator of this correction at 29° much above 900, we may still assume that value without error, and our formula becomes

(H.) $$D = 60000 (\log H - \log h) \times \left(1 + \frac{T+t-58}{900}\right)$$

$$D = 60000 (\log H - \log h)$$

correct at 29° Fahr. $\pm \frac{1}{900}$ for each 1° of the sum of temperatures above or below 58° Fahr., or $\pm \frac{1}{450}$ for each 1° of the mean above or below 29° Fahr.

For all ordinary observations this can be taken as correct at 30° Fahr. for facility of computation, making a difference of only 10 feet in 4,500 of altitude.

(H'.) $$D = 60000 (\log H - \log h) \times \left(1 + \frac{T+t-60}{900}\right)$$

This is the simplest form in which an accurate formula can be put.

Prof. Airey's table, which was originally made for the purpose of graduating aneroids to a scale of feet, gives the height of the corrected mercurial column in inches for each fifty feet of altitude at 50° Fahr. On reducing this to the formula we have given, we find that his constants have values agreeing more nearly with the results of actual observations than perhaps any others that have been proposed. His standard of air temperature at 50° Fahr., or 10° Centigrade, is also very convenient, as it is near the temperature at which ordinary observations are taken, and the corrections will be small, and in some cases may be disregarded.

His factor for temperature correction of $\frac{1}{1000}$ for each 1° Fahr. of the sum of the two temperatures, above or below 100°, is the most convenient possible.

We also find that the formula derived from his table agrees with Plantamour's at 45½° Fahr., and only differs above and below by the difference of temperature correction, in which Prof. Airey is probably the most correct.

The above reasons, taken in connection with the fact that his table is extensively used in graduating aneroids, leads us to prefer his values to all others for computation of heights. His table, reduced to a formula at 50° Fahr., is,

(I.) $$D = 62759 (\log H - \log h)\left(1 + \frac{T+t-100}{1000}\right)$$

the coefficient of which involves too much labor in multiplying, to make it useful. When reduced to 32° Fahr. the coefficient for pressure becomes more simple, but the factor for temperature $\frac{1}{964}$ becomes inconvenient.

See formula (D').

We have, therefore, computed a table (No. IV.), from Prof. Airey's values, the quantities of which will be given by either of the formulæ (D') or (I) at a temperature of 50° Fahr.

We then recommend for computation of altitudes by the aneroid:

1. Table IV., based on Prof. Airey's constants, and using his correction for air temperature of $\frac{T+t-100}{1000}$ of the tabular quantities. This is the simplest and most accurate.

2. When this table is not at hand, the formula,

(H'.) $$D = 60000\ (\log H - \log h) \times \left(\frac{T+t-60}{900}\right)$$

or any table based upon Plantamour's formula with La Place's correction for temperature.

3. Tables based upon any other of the formulæ before given.

4. Where no tables of any kind are at hand,

(G'.) $$D = 55000\ \frac{H-h}{H+h} + \frac{1}{500}$$

for each 1° Fahr. of mean temperature above or below 55° Fahr.

## MODE OF OBSERVING WITH THE ANEROID.

On the manner of using any instrument depends in a great measure the accuracy of the results obtained from it. This is especially true of such instruments as barometers, where greater care in use and accuracy of observation are necessary than with less sensitive and fragile apparatus.

When an aneroid barometer has been adjusted and compared, as before described, and it is desired to ascertain the reading of the scale at any place, the instrument should be held horizontally, and the bottom of the case gently tapped with the ends of the fingers. This must not be so hard as to make the index vibrate and settle at different points, as it will if struck too violently. By turning the aneroid, handle down, and bringing it gently back to a horizontal position, the index will generally be found a little to the left of its true position; a gentle tap, the force of which will easily be determined by experiment, causes it to return to its

proper position. It should always be tapped with about this degree of force.

Some instruments, especially the larger ones, will indicate correctly without the tap, but not invariably, and it is always safest to tap them as described.

In reading the scale great care should be taken to avoid parallax. This error in small pocket aneroids may amount to one or two hundredths of an inch. It is better for inexperienced observers to look with one eye, placed in range with, or over, the centre of the dial. In all observations note the reading and also the temperature, both of the instrument and the air. If for taking differences of level, note also the time. Do not on any account let the sun shine on the barometer; it is sure to derange the readings.

The aneroid should always be carried with a guard or strap to prevent accident.

To insure accuracy in obtaining differences of level, simultaneous observations at the two points, as is usually done with mercurial barometers, is undoubtedly the best method.

It frequently happens, however, with the engineer, that he requires levels over a number of points at some distances apart, which it will take some time, perhaps half a day, or all day, to pass over. In this case simultaneous observations are impracticable. Perhaps the engineer has but one aneroid. It becomes necessary then to pass successively over the several points and note the heights shown by the index, together with the temperatures of the instrument and the air, and also the time. If possible, it is desirable to have an assistant at some point to read a barometer hourly and take the temperatures, so as to note any changes that may occur during the continuance of the observations. It is not necessary that this should be an accurate instrument; any of the ordinary hotel or store barometers will answer the purpose. The observations should, however, be reduced to 32°. If the engineer have no second barometer, and there are none in use in the vicinity, it will be necessary to correct his observations by returning to the starting point and taking the reading. An excellent method is to go over the points in one direction, and return, taking them over again. When practicable, this is usually the best way, even if an assistant takes hourly observations at the same point. The average of the results obtained from the two observations at each point gives a great degree of accuracy.

If, on a return to the starting-point, or from the subsidiary barometer, it is found that the height has changed, as is usually the case, it is best first to reduce all the readings to the same level as though the barometer had not changed, by adding or subtracting the proper quantities, proportional to the time of the observations, to the observed heights at each point. If two readings have been taken at each station all the heights can be computed and the average of the final quantities taken.

To the station reading must also be applied the corrections for the temperature of the instrument and the error of scale readings, if there are any. Having now the correct reading of the barometer and the temperature of the air at the several stations, if we have no table of heights such as Table IV., Williamson's, Guyot's, or Galbraith's, at hand, we must have recourse to our formula (II'). If the barometer has a scale of feet made from a correct formula, the readings can be taken from that, approximately, by noting the feet opposite the proper reading of the scale of inches. The readings cannot originally be taken from this scale for accurate observations, on account of the difficulty of making the necessary corrections. It is a good plan, however, to note both scales.

In using the formula (II') for a number of consecutive stations, it is not necessary to take the difference of the logs for each two, and multiply by 60,000; for $C(\log H - \log h) = C, \log H - C \log h$, so we have only to find $60{,}000 \times \log H$ for each station, and afterwards take the differences and correct for temperature of the air between each two stations.

Ruling a page into six columns, let us place the corrected barometrical readings, the temperature of the air, and the tabular numbers, in the first three. If we have no table, take the log of the height of the barometer move the point four places to the right, multiply by six and place the result in the third column for the tabular number. We then take the difference of the tabular numbers, make the proper correction for the temperature of the air between the two stations, and make a column of differences. Owing to the different amounts of correction for air temperature, the difference of the sums of the positive and negative differences is not generally equal to the correct difference of the two ends of the survey, obtained by direct comparison. The discrepancy should be adjusted among all the numbers in the difference column, adding to the + quantities and subtracting from the — quantities, or *vice versa*, so as to make their sums of the same magnitude. The new difference thus obtained we put in the

column of corrected differences. These added or subtracted successively forms the column of total heights.

This is altogether the best method of treating barometrical observations taken in a series. An example is given below from notes actually taken while recently visiting the Hoosac tunnel. The notes were taken with no view to great accuracy. But one small pocket thermometer was used both for the instrument and air.

An extra aneroid was left at the Engineer's office, at North Adams, and there observed every hour. By this the proportional corrections were made for the observations to be reduced to the same level. It will be observed that the barometer was falling quite rapidly, the notes being taken between 9 A. M and 4 P. M.

The original readings are also given. At the end are the heights of such of the points as have been determined by the level, and the errors of the barometrical results.

The tabular numbers are taken from Williamson's tables.*

| STATIONS. | Observed heights. | Corrected heights. | Temp. of air. | Tabular number. | Difference. | Corrected Difference. | Total height. | Height by level. | Error of barometer. |
|---|---|---|---|---|---|---|---|---|---|
| | | | ° | | | | | | |
| Engineer's office..... | 29.70 | 29 70 | 62 | 28547 | | | 711 | | |
| West end of tunnel.... | 29.63 | 29.65 | 59 | 28503 | + 47 | + 47 | 758 | 766 | — 8 |
| East end of brickwork. | 29.62 | 29.65 | 55 | 28503 | 0 | 0 | 758 | 772 | —14 |
| Top of west shaft..... | 29.27 | 29.31 | 69 | 28200 | + 323 | + 324 | 1082 | 1096 | —14 |
| Bottom of west shaft .. | 29.58 | 29.64 | 53 | 28494 | — 313 | — 312 | 770 | 778 | — 8 |
| Extreme end of heading. | 29.53 | 29.61 | 62 | 28467 | + 29 | + 29 | 799 | 805 | — 6 |
| End of working face.... | 29.54 | 29.62 | 62 | 28476 | — 10 | — 10 | 789 | 791 | — 2 |
| Top of west shaft..... | 29.21 | 29.31 | 70 | 28200 | + 297 | + 298 | 1087 | 1096 | — 9 |
| Engineer's office..... | 29.57 | 29.70 | 69 | 28547 | — 377 | — 376 | 711 | | |
| | | | | | + 696 | | | | |
| | | | | | — 700 | | | | |
| | | | | Diff.... | — 4 | | | | |

* Table IV. was not computed at the time these were taken.

The observations were made with the pocket barometer before mentioned. The height of the Engineer's office was assumed at 711, or ten feet by barometer above the level of the railroad track at the North Adams Station, which is 701 above the base by level.

The day before the above levels were observed, notes were taken on the train from Hartford to North Adams. Those between Springfield and North Adams were taken in the evening, by the light of the candles burning in the car, and the reading could be but imperfectly seen. The results, however, are given in the following table. They were reduced from the observed heights of the barometer, assuming Springfield to be 75 feet, and North Adams Station 701 feet above base.

On the day after the observations taken at the west end of the tunnel the writer was driven over the mountain to the east end, and took readings at the points given in the following table. The corrections were made by means of a mercurial barometer, read every hour in North Adams.

The computed heights are given in the first column, as found from the reading of the aneroid, in inches, and computed by Plantamour's formula (Williamson's tables) and La Place's correction for temperature, giving the same results as formula (H).

The second column contains the actual heights by the level, and the third the errors of the barometrical heights.

| | Heights by Barometer. | Heights by Level. | Error of Barom. | |
|---|---|---|---|---|
| Office at Hartford..... | 85 | | | |
| Hartford Station..... | 28 | | | |
| Springfield Station..... | 75 | | | |
| Washington Station..... | 1440 | 1450 | - 10 | |
| Pittsfield Station..... | 997 | 968 | + 29 | |
| N. Adams Station..... | 701 | | | |
| Engineer's office..... | 711 | | | |
| West end of tunnel ..... | 758 | 766 | - 8 | |
| East end of brickwork.... | 758 | 772 | - 14 | |
| Top of west shaft..... | 1087 | 1096 | - 11 | |
| Bottom west shaft..... | 770 | 778 | - 8 | |
| Extreme end of heading.. | 799 | 805 | - 6 | 5,265 feet from west end. |
| End of working face..... | 789 | 791 | - 2 | 4,970 feet from west end. |

| | Heights by Barometer. | Heights by Level. | Error of Barom. | |
|---|---|---|---|---|
| Engineer's office..... | 711 | | | |
| N. Adams Station..... | 701 | | | |
| Five Points on road..... | 941 | | | |
| Station 69 on road..... | 1310 | 1304 | + 6 | |
| Watering place on road.. | 1564 | 1552 | + 12 | |
| West summit..... | 2038 | 2013 | + 25 | On stage road. |
| Top of central shaft..... | 1885 | 1865 | + 20 | |
| Kemp's brook..... | 1796 | 1771 | + 25 | |
| Cold river..... | 1979 | | | On stage road. |
| East summit..... | 2182 | 2173 | + 9 | On stage road. |
| East end of tunnel..... | 759 | 766 | - 7 | |
| | | | 192 | |
| | | | 12.8 f | Average error. |

Where long lines are to be levelled over, two aneroids become necessary to insure accuracy. In this case one observer should pass over the ground in advance of the other, a distance of at least that between the farthest apart of any two stations; and it is perhaps better to include several between the two instruments as they successively pass over the line.

All the points observed should be marked, and each observer should note the time of his observations. Simultaneous observations should then be computed between the point of commencement and where the first observer is when the second commences, then between that point and where the first observer is when the second arrives at the end of the first distance, and so on, forming a chain of simultaneous observations, or nearly so, for any distance desired. A sufficient number of observations should be taken to insure some one of those taken by the first observer being within a few minutes of the time when the second arrives at one of the principal stations of comparison. Except in case of a storm, a small difference of time in the observations may be disregarded.

For the intermediate stations we can use the methods before given to ascertain the elevations, which should be made up from the readings of both instruments and the average taken.

HOW TO PURCHASE AN ANEROID.

If you are not a good judge of the instrument, go to the best maker or seller.

If you want accuracy prefer a brass case. The back plate of the mechanism being secured to the case, if they are of different metals, as brass and silver, the different rate of expansion by heat sometimes causes error.

Examine the dial and see if the divisions are *engraved.* If they are *stamped* upon it the instrument is probably worthless for accurate observations. The dial should be electro-plated, and not washed. See that the index is fine and slender, and lies close to the dial. It is best of blued steel. Have no central pointer for showing the position of the index. There should be a small steel pointer attached to the rim, as has been described. See that the dial has the number of inches you desire. From six to ten inches is a good range for engineering purposes. About three quarters of the circumference can be made to read accurately.

Tap the instrument gently on the bottom and see where the index settles. Now turn the handle down, and bring it gently back to a horizontal position. The index should not be more than .02 or .03 from its former position, and a gentle tap should always bring it exactly back to the same reading. Many of the larger aneroids, and some of the small ones, will come back to the same position without tapping. To test the compensation in a pocket aneroid, if the temperature is below 60°, put it in an inside pocket for 20 or 30 minutes; if not compensated it will show a movement of the index. It should be allowed to cool again, and be re-examined to see if it has risen or fallen during the experiment.

For a pocket aneroid buy the largest that can be conveniently carried in the pocket, and not the very smallest size. Two to two and one-fourth inches is a convenient size, and can be made accurate.

If the dial has a scale of feet, see that it is graduated according to some correct formula, by taking off the numbers corresponding to each inch and comparing them with some known table or formula.

The instrument should have a case, so that the heat of the hand shall not derange it when observing.

It is better also to have a thermometer in the dial inside the scale, and dropped lower down, so as not to interfere with the index.

Instruments that have the zero of the foot scale at 30 inches, particu-

larly those having movable scales are generally erroneously graduated, the same scale being commenced at 30 that should be commenced at 31 inches; they are moreover inconvenient to use.

The prices of first class aneroids, such as are made by Pitkin of London, and sold by the best English dealers, should be, in the United States, about 50 per cent. more than the London prices. For an instrument in brass case, such as above described, reading from 24 to 31 inches, the price in gold should be about—

$30 for pocket size.
35 for medium size, and
40 for the large size.

The ordinary French aneroids can be had for about half the above.

# TABLE I.

## Reduction of Mercurial Column to 32° Fahr.

*Brass scale to barometer correct at 62° Fahr.*

| TEMP. | 30″ | 25″ | 20″ | 15″ | 10″ | 1″ | NOTES. |
|---|---|---|---|---|---|---|---|
| ° | | | | | | | |
| 32 | .009 | .008 | .006 | .005 | .003 | .000 | The quantities are to be subtracted from mercurial column to agree with aneroid. The reason of there being a correction at 32° is that the brass scale is correct at 62° and makes a correction necessary at 32°. If the scale is of any other material than brass the difference of expansion of the two materials must be allowed above and below 62° Fahr. |
| 35 | .017 | .015 | .012 | .009 | .006 | .001 | |
| 40 | .031 | .026 | .021 | .015 | .010 | .001 | |
| 45 | .044 | .037 | .030 | .022 | .015 | .001 | |
| 50 | .058 | .048 | .038 | .029 | .019 | .002 | |
| 55 | .071 | .059 | .047 | .036 | .024 | .002 | |
| 60 | .084 | .070 | .056 | .042 | .028 | .003 | |
| 65 | .098 | .082 | .065 | .049 | .033 | .003 | |
| 70 | .111 | .093 | .074 | .056 | .037 | .004 | |
| 75 | .125 | .104 | .083 | .062 | .042 | .004 | |
| 80 | .138 | .115 | .092 | .069 | .046 | .005 | |
| 85 | .151 | .126 | .101 | .076 | .050 | .005 | |
| 90 | .164 | .137 | .110 | .082 | .055 | .005 | |
| 95 | .178 | .148 | .118 | .089 | .059 | .006 | |
| 100 | .191 | .159 | .127 | .096 | .064 | .006 | |

# TABLE II.

## Latitude Correction.

*Lat. 0° to 45° mercurial column too long; 45° to 90° too short.*

| LAT. | LAT. | 30″ | 20″ | 10″ | 1″ | NOTES. |
|---|---|---|---|---|---|---|
| ° | ° | | | | | |
| 0 | 90 | .080 | .053 | .027 | .003 | Subtract from height of mercury from 0° to 45°, and add from 45° to 90°. |
| 5 | 85 | .079 | .052 | .026 | .003 | |
| 10 | 80 | .075 | .050 | .025 | .003 | |
| 15 | 75 | .069 | .046 | .023 | .002 | |
| 20 | 70 | .061 | .041 | .020 | .002 | |
| 25 | 65 | .051 | .034 | .017 | .002 | |
| 30 | 60 | .040 | .027 | .013 | .001 | |
| 35 | 55 | .027 | .018 | .009 | .001 | |
| 40 | 50 | .014 | .009 | .005 | .001 | |
| 45 | 45 | .000 | .000 | .000 | .000 | |

# TABLE III.

Correction for Decrease of Gravity in Altitude, acting on the Density of the Mercury.

| ALT. | CORRECTION. INCHES. | CORRECTION. FT. ALT. | NOTES. |
|---|---|---|---|
| 0 | .000 | 0 | The corrections in the column of inches are to be subtracted from the height of the mercury, to compare with aneroid. |
| 1,000 | .003 | 2.5 | |
| 2,000 | .005 | 5.2 | |
| 3,000 | .008 | 7.9 | The column of corrections for feet of altitude is the amount to be added to the results obtained from mercurial observations, to get the true difference of altitude between two stations. |
| 4,000 | .011 | 10.8 | |
| 5,000 | .013 | 13 7 | |
| 6,000 | .015 | 16.7 | |
| 7,000 | .017 | 19.9 | |
| 8,000 | .019 | 23.1 | |
| 9,000 | .021 | 26 4 | |
| 10,000 | .023 | 29.8 | |
| 11,000 | .025 | 33.3 | |
| 12,000 | .026 | 36.9 | |
| 13,000 | .028 | 40 6 | |
| 14,000 | .030 | 44.4 | |
| 15,000 | .031 | 48 3 | |
| 16,000 | .032 | 52.3 | |
| 17,000 | .034 | 56.4 | |
| 18,000 | .035 | 60.5 | |
| 19,000 | .036 | 64.8 | |
| 20,000 | .037 | 69.2 | |

# TABLE IV.

Table for estimating Heights by the Barometer.

$$\textit{Correction for temperature of the air} = \frac{T + t - 100}{1000}\ \textit{Fahr.}$$

| BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. |
|---|---|---|---|---|---|---|---|
| 24.00 | 6976 | 24.33 | 6603 | 24.66 | 6236 | 24.99 | 5874 |
| .01 | 6964 | .34 | 6592 | .67 | 6225 | 25.00 | 5863 |
| .02 | 6953 | .35 | 6581 | .68 | 6214 | .01 | 5853 |
| .03 | 6941 | .36 | 6570 | .69 | 6203 | .02 | 5842 |
| .04 | 6930 | .37 | 6559 | 24.70 | 6192 | .03 | 5831 |
| .05 | 6919 | .38 | 6547 | .71 | 6181 | .04 | 5820 |
| .06 | 6907 | .39 | 6536 | .72 | 6170 | .05 | 5809 |
| .07 | 6896 | 24.40 | 6525 | .73 | 6159 | .06 | 5798 |
| .08 | 6885 | .41 | 6514 | .74 | 6148 | .07 | 5787 |
| .09 | 6873 | .42 | 6503 | .75 | 6137 | .08 | 5776 |
| 24.10 | 6862 | .43 | 6491 | .76 | 6126 | .09 | 5765 |
| .11 | 6851 | .44 | 6480 | .77 | 6115 | 25.10 | 5754 |
| .12 | 6840 | .45 | 6469 | .78 | 6104 | .11 | 5744 |
| .13 | 6828 | .46 | 6458 | .79 | 6093 | .12 | 5733 |
| .14 | 6817 | .47 | 6447 | 24.80 | 6082 | .13 | 5722 |
| .15 | 6806 | .48 | 6435 | .81 | 6071 | .14 | 5711 |
| .16 | 6795 | .49 | 6424 | .82 | 6060 | .15 | 5700 |
| .17 | 6783 | 24.50 | 6413 | .83 | 6049 | .16 | 5689 |
| .18 | 6772 | .51 | 6402 | .84 | 6038 | .17 | 5679 |
| .19 | 6761 | .52 | 6391 | .85 | 6027 | .18 | 5668 |
| 24.20 | 6750 | .53 | 6380 | .86 | 6016 | .19 | 5657 |
| .21 | 6738 | .54 | 6369 | .87 | 6005 | 25.20 | 5646 |
| .22 | 6727 | .55 | 6357 | .88 | 5994 | .21 | 5635 |
| .23 | 6716 | .56 | 6346 | .89 | 5983 | .22 | 5624 |
| .24 | 6705 | .57 | 6335 | 24.90 | 5972 | .23 | 5613 |
| .25 | 6693 | .58 | 6324 | .91 | 5962 | .24 | 5602 |
| .26 | 6682 | .59 | 6313 | .92 | 5951 | .25 | 5592 |
| .27 | 6671 | 24.60 | 6302 | .93 | 5940 | .26 | 5581 |
| .28 | 6659 | .61 | 6291 | .94 | 5929 | .27 | 5570 |
| .29 | 6648 | .62 | 6280 | .95 | 5918 | .28 | 5559 |
| 24.30 | 6637 | .63 | 6269 | .96 | 5907 | .29 | 5548 |
| .31 | 6626 | .64 | 6258 | .97 | 5896 | 25.30 | 5537 |
| .32 | 6615 | .65 | 6247 | .98 | 5885 | .31 | 5527 |

## TABLE IV.—Continued.

| BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. | BAROMETER. | HEIGHT IN FEET. |
|---|---|---|---|---|---|---|---|
| 25.32 | 5516 | 25.70 | 5110 | 26.08 | 4710 | 26.46 | 4317 |
| .33 | 5505 | .71 | 5099 | .09 | 4700 | .47 | 4306 |
| 34 | 5494 | .72 | 5089 | 26 10 | 4690 | .48 | 4296 |
| .35 | 5483 | .73 | 5078 | .11 | 4679 | .49 | 4286 |
| .36 | 5473 | .74 | 5068 | .12 | 4669 | 26.50 | 4275 |
| .37 | 5462 | .75 | 5057 | .13 | 4658 | .51 | 4265 |
| .38 | 5451 | .76 | 5046 | .14 | 4648 | .52 | 4255 |
| .39 | 5440 | .77 | 5036 | .15 | 4638 | .53 | 4245 |
| 25.40 | 5429 | .78 | 5025 | .16 | 4627 | .54 | 4234 |
| .41 | 5419 | .79 | 5015 | .17 | 4617 | .55 | 4224 |
| .42 | 5408 | 25.80 | 5004 | .18 | 4607 | .56 | 4214 |
| .43 | 5397 | .81 | 4994 | .19 | 4596 | .57 | 4204 |
| .44 | 5387 | .82 | 4983 | 26 20 | 4586 | .58 | 4193 |
| .45 | 5376 | .83 | 4973 | .21 | 4575 | .59 | 4183 |
| .46 | 5365 | .84 | 4962 | .22 | 4565 | 26.60 | 4173 |
| .47 | 5355 | 85 | 4952 | .23 | 4554 | .61 | 4163 |
| .48 | 5344 | .86 | 4941 | .24 | 4544 | .62 | 4152 |
| .49 | 5333 | .87 | 4931 | .25 | 4533 | .63 | 4142 |
| 25.50 | 5323 | .88 | 4920 | .26 | 4523 | .64 | 4132 |
| .51 | 5312 | .89 | 4910 | .27 | 4512 | .65 | 4122 |
| .52 | 5301 | 25.90 | 4899 | .28 | 4502 | .66 | 4111 |
| .53 | 5291 | .91 | 4889 | .29 | 4492 | .67 | 4101 |
| .54 | 5280 | 92 | 4878 | 26.30 | 4481 | .68 | 4091 |
| .55 | 5270 | .93 | 4868 | .31 | 4471 | .69 | 4081 |
| .56 | 5259 | .94 | 4857 | .32 | 4461 | 26.70 | 4071 |
| .57 | 5248 | .95 | 4847 | .33 | 4450 | .71 | 4060 |
| .58 | 5238 | .96 | 4836 | .34 | 4440 | .72 | 4050 |
| .59 | 5227 | .97 | 4826 | .35 | 4430 | .73 | 4040 |
| 25.60 | 5217 | .98 | 4815 | .36 | 4419 | .74 | 4030 |
| .61 | 5206 | .99 | 4805 | .37 | 4409 | .75 | 4019 |
| .62 | 5195 | 26.00 | 4794 | .38 | 4399 | .76 | 4009 |
| 63 | 5185 | .01 | 4784 | .39 | 4389 | .77 | 3999 |
| .64 | 5174 | .02 | 4773 | 26.40 | 4378 | .78 | 3989 |
| 65 | 5163 | .03 | 4763 | .41 | 4368 | .79 | 3979 |
| 66 | 5153 | .04 | 4752 | .42 | 4358 | 26.80 | 3968 |
| 67 | 5142 | .05 | 4742 | .43 | 4347 | .81 | 3958 |
| .68 | 5131 | .06 | 4731 | .44 | 4337 | .82 | 3948 |
| .69 | 5121 | .07 | 4721 | .45 | 4327 | .83 | 3938 |

## TABLE IV.—Continued.

| BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. |
|---|---|---|---|---|---|---|---|
| 26.84 | 3928 | 27.22 | 3544 | 27.60 | 3166 | 27.98 | 2794 |
| .85 | 3918 | .23 | 3534 | .61 | 3156 | .99 | 2784 |
| .86 | 3907 | .24 | 3524 | .62 | 3147 | 28.00 | 2774 |
| .87 | 3897 | .25 | 3514 | .63 | 3137 | .01 | 2765 |
| .88 | 3887 | .26 | 3504 | .64 | 3127 | .02 | 2755 |
| .89 | 3877 | .27 | 3494 | .65 | 3117 | .03 | 2745 |
| 26.90 | 3866 | .28 | 3484 | .66 | 3107 | .04 | 2735 |
| .91 | 3856 | .29 | 3474 | .67 | 3097 | .05 | 2726 |
| .92 | 3846 | 27.30 | 3464 | .68 | 3087 | .06 | 2716 |
| .93 | 3836 | .31 | 3454 | .69 | 3078 | .07 | 2706 |
| .94 | 3826 | .32 | 3444 | 27.70 | 3068 | .08 | 2696 |
| .95 | 3816 | .33 | 3434 | 71 | 3058 | .09 | 2687 |
| .96 | 3806 | .34 | 3424 | .72 | 3048 | 28.10 | 2677 |
| .97 | 3796 | .35 | 3414 | .73 | 3038 | .11 | 2667 |
| .98 | 3786 | .36 | 3404 | .74 | 3029 | .12 | 2658 |
| .99 | 3776 | .37 | 3394 | .75 | 3019 | .13 | 2648 |
| 27.00 | 3765 | .38 | 3385 | .76 | 3009 | .14 | 2638 |
| .01 | 3755 | .39 | 3375 | .77 | 2999 | .15 | 2629 |
| .02 | 3745 | 27.40 | 3365 | .78 | 2989 | .16 | 2619 |
| .03 | 3735 | .41 | 3355 | .79 | 2980 | .17 | 2609 |
| .04 | 3725 | .42 | 3345 | 27.80 | 2970 | .18 | 2600 |
| .05 | 3715 | .43 | 3335 | .81 | 2960 | .19 | 2590 |
| .06 | 3705 | .44 | 3325 | .82 | 2950 | 28.20 | 2580 |
| .07 | 3695 | .45 | 3315 | .83 | 2940 | .21 | 2571 |
| .08 | 3685 | .46 | 3305 | .84 | 2931 | .22 | 2561 |
| .09 | 3675 | .47 | 3295 | .85 | 2921 | .23 | 2551 |
| 27.10 | 3665 | .48 | 3285 | .86 | 2911 | .24 | 2542 |
| .11 | 3655 | .49 | 3275 | .87 | 2901 | .25 | 2532 |
| .12 | 3645 | 27.50 | 3265 | .88 | 2891 | .26 | 2522 |
| .13 | 3635 | .51 | 3255 | .89 | 2882 | .27 | 2513 |
| .14 | 3625 | .52 | 3245 | 27.90 | 2872 | .28 | 2503 |
| .15 | 3614 | .53 | 3235 | .91 | 2862 | .29 | 2493 |
| .16 | 3604 | .54 | 3225 | .92 | 2852 | 28.30 | 2484 |
| .17 | 3594 | .55 | 3216 | .93 | 2843 | .31 | 2474 |
| .18 | 3584 | .56 | 3206 | .94 | 2833 | .32 | 2464 |
| .19 | 3574 | .57 | 3196 | .95 | 2823 | .33 | 2455 |
| 27.20 | 3564 | .58 | 3186 | .96 | 2813 | .34 | 2445 |
| .21 | 3554 | .59 | 3176 | .97 | 2804 | .35 | 2435 |

## TABLE IV.—Continued.

| BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. |
|---|---|---|---|---|---|---|---|
| 28.36 | 2426 | 28.74 | 2063 | 29.12 | 1705 | 29.50 | 1352 |
| .37 | 2416 | .75 | 2054 | .13 | 1696 | .51 | 1342 |
| .38 | 2406 | .76 | 2045 | .14 | 1686 | .52 | 1333 |
| .39 | 2396 | .77 | 2035 | .15 | 1677 | .53 | 1324 |
| 28.40 | 2387 | .78 | 2026 | .16 | 1668 | .54 | 1315 |
| .41 | 2378 | .79 | 2017 | 17 | 1658 | .55 | 1305 |
| .42 | 2368 | 28.80 | 2007 | .18 | 1649 | .56 | 1296 |
| .43 | 2358 | .81 | 1998 | .19 | 1639 | .57 | 1287 |
| .44 | 2349 | .82 | 1989 | 29.20 | 1630 | .58 | 1278 |
| .45 | 2339 | .83 | 1979 | 21 | 1621 | .59 | 1268 |
| .46 | 2330 | .84 | 1970 | .22 | 1611 | 29.60 | 1259 |
| .47 | 2320 | .85 | 1960 | .23 | 1602 | 61 | 1250 |
| .48 | 2310 | .86 | 1951 | .24 | 1593 | .62 | 1241 |
| .49 | 2301 | .87 | 1941 | .25 | 1583 | .63 | 1232 |
| 28.50 | 2291 | .88 | 1932 | .26 | 1574 | .64 | 1222 |
| .51 | 2282 | .89 | 1922 | .27 | 1565 | .65 | 1213 |
| .52 | 2272 | 28.90 | 1913 | .28 | 1555 | .66 | 1204 |
| .53 | 2262 | .91 | 1903 | .29 | 1546 | .67 | 1195 |
| .54 | 2253 | .92 | 1894 | 29.30 | 1536 | .68 | 1186 |
| .55 | 2243 | .93 | 1884 | .31 | 1527 | .69 | 1177 |
| .56 | 2234 | .94 | 1875 | .32 | 1518 | 29.70 | 1167 |
| .57 | 2224 | .95 | 1865 | .33 | 1509 | .71 | 1158 |
| .58 | 2215 | .96 | 1856 | .34 | 1500 | .72 | 1149 |
| .59 | 2205 | .97 | 1846 | .35 | 1490 | .73 | 1140 |
| 28.60 | 2196 | .98 | 1837 | .36 | 1481 | .74 | 1131 |
| .61 | 2186 | .99 | 1827 | .37 | 1472 | .75 | 1122 |
| .62 | 2177 | 29.00 | 1818 | .38 | 1463 | .76 | 1113 |
| .63 | 2167 | .01 | 1809 | .39 | 1453 | .77 | 1103 |
| .64 | 2158 | .02 | 1799 | 29.40 | 1444 | .78 | 1094 |
| .65 | 2148 | .03 | 1790 | .41 | 1435 | .79 | 1085 |
| .66 | 2139 | .04 | 1780 | .42 | 1426 | 29.80 | 1076 |
| .67 | 2129 | .05 | 1771 | .43 | 1416 | .81 | 1067 |
| .68 | 2120 | .06 | 1762 | .44 | 1407 | .82 | 1058 |
| .69 | 2110 | .07 | 1752 | .45 | 1398 | .83 | 1049 |
| 28.70 | 2101 | .08 | 1743 | .46 | 1389 | .84 | 1040 |
| .71 | 2091 | .09 | 1733 | .47 | 1379 | .85 | 1030 |
| .72 | 2082 | 29.10 | 1724 | .48 | 1370 | .86 | 1021 |
| .73 | 2073 | .11 | 1715 | .49 | 1361 | .87 | 1012 |

## TABLE IV. Continued.

| BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. | BAROM-ETER. | HEIGHT IN FEET. |
|---|---|---|---|---|---|---|---|
| 29.88 | 1003 | 30.17 | 740 | 30.45 | 488 | 30.73 | 239 |
| .89 | 994 | .18 | 731 | .46 | 479 | .74 | 230 |
| 29.90 | 985 | .19 | 722 | .47 | 470 | .75 | 221 |
| .91 | 976 | 30.20 | 713 | .48 | 461 | .76 | 212 |
| .92 | 967 | .21 | 704 | .49 | 452 | .77 | 203 |
| .93 | 958 | .22 | 695 | 30.50 | 443 | .78 | 194 |
| .94 | 949 | .23 | 686 | .51 | 435 | .79 | 186 |
| .95 | 939 | .24 | 677 | .52 | 426 | 30.80 | 177 |
| .96 | 930 | .25 | 667 | .53 | 417 | .81 | 168 |
| .97 | 921 | .26 | 658 | .54 | 408 | .82 | 159 |
| .98 | 912 | .27 | 649 | 55 | 399 | .83 | 150 |
| .99 | 903 | .28 | 640 | .56 | 390 | .84 | 141 |
| 30.00 | 894 | .29 | 631 | .57 | 381 | .85 | 133 |
| .01 | 885 | 30.30 | 622 | .58 | 372 | .86 | 124 |
| .02 | 876 | .31 | 613 | .59 | 363 | .87 | 115 |
| .03 | 867 | .32 | 604 | 30.60 | 354 | .88 | 106 |
| 04 | 858 | .33 | 595 | .61 | 346 | .89 | 97 |
| .05 | 849 | .34 | 586 | .62 | 337 | 30.90 | 88 |
| .06 | 840 | .35 | 577 | .63 | 328 | .91 | 80 |
| .07 | 831 | .36 | 568 | .64 | 319 | .92 | 71 |
| .08 | 821 | .37 | 559 | .65 | 310 | .93 | 62 |
| .09 | 812 | .38 | 550 | .66 | 301 | .94 | 53 |
| 30 10 | 803 | .39 | 542 | .67 | 292 | .95 | 44 |
| .11 | 794 | 30.40 | 533 | .68 | 283 | .96 | 86 |
| .12 | 785 | .41 | 524 | .69 | 274 | .97 | 27 |
| .13 | 776 | .42 | 515 | 30.70 | 265 | .98 | 18 |
| .14 | 767 | .43 | 506 | .71 | 257 | .99 | 9 |
| 15 | 758 | .44 | 497 | .72 | 248 | 31.00 | 0 |
| .16 | 749 | | | | | | |

XXIV.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

At a meeting of the Society, Jan. 18th, 1871.

## DESCRIPTION OF THE NEW WROUGHT-IRON BRIDGE AT BRIDGEPORT, CT.

A paper read by Mr. ALFRED P. BOLLER, C. E., member of the Society.

This bridge crosses the Pequonnock river at an angle of about 60 deg., and comprises a total length of 845 feet. Of this length 345 feet are taken up on the west side by an embankment between retaining walls, gradually rising with a grade of 1.66 feet per 100. The superstructure of 420 feet, total length, consists of three fixed spans of 70 feet each, and one draw-span of 210 feet over all (centre measurements). The roadway on the permanent spans *is thirty feet in the clear between trusses*, but is contracted at the draw-span to 23 feet, as shown on the drawing. The sidewalks on either side of the trusses are six feet in the clear, except on the draw-span, where they are five feet. The above are unusual dimensions, but so required by the Commissioners, to accomodate a heavy and increasing traffic.

The principle of truss adopted will be at once recognized as that first recommended by Mr. Whipple, and from the fact that the posts are vertical, this system commends itself for city bridges (where trusses are unavoidable), for the reason that such posts are susceptible of more æsthetic treatment than inclined ones. The question of the appearance of such

structures has too often but little consideration from engineers and town committees in these days of close competition, which is much to be regretted, for certainly an object that is so prominent in cities and towns as a bridge, observed from necessity perhaps more than any other public or private work, demands something more than simple constructive or economical considerations.

Permanent Span.—The trusses of the permanent spans are 5 feet $8\frac{3}{4}$ inches deep, and are broken up into twelve rectangular panels. Each upper chord is 19 inches wide, and is composed of varying thicknesses of boiler-plate riveted to two six-inch rolled channel bars and one six-inch flanged beam. The lower chord is formed from weldless links, whose heads have been made by upsetting. These links, the length of one panel, are joined by carefully turned pins, which pins also form the connection for the diagonal braces and posts. The braces are also links, formed as above, the connection with the upper chord being by means of a pin passing through the channel bars.

The vertical posts are in pairs, and are the patent wrought-iron column of the Phœnix Iron Co. They are formed by riveting together four segments of a true cylinder by means of flanges which are turned outward. Cast-iron caps and bases, turned and fitted, form the bearings between the chords. It should be remarked, in connection with the braces, that the counter rods have turn-buckles upon them, forming the only adjustable feature in the truss. The floor-girders (of which there are three in each span) are trussed $2\frac{1}{2}$ feet deep, as shown on drawing, and have their bearing upon the base castings through the medium of projecting brackets. The upper member consists of two six-inch channel bars, passing either side of posts with a plate ten inches wide riveted on top. The channel bars project beyond the trusses to support sidewalks. Horizontal sway braces, intersecting in a ring, are attached to the floor-girders at their bearing points on the trusses. The three-inch spruce planking which forms the roadway is supported upon longitudinal stringers of $4 \times 12$ white pine, placed 18 inches apart. The sidewalks are planed yellow pine plank two inches thick. The railing is of simple but effective construction, and made from two very light tee bars with diagonal strips riveted to the webs. The diagonals intersect in a cast-iron boss, and the top rail is finished off with a half round strip riveted upon it.

The Draw-span, at present the largest self-sustaining draw in the

Eastern States, is supported upon a Parry-antifriction pivot and a circular drum 28 feet diameter, of wrought and cast iron, bearing upon chilled wheels in a live ring. At intervals heavy diagonal rods connect the bottom flange of the drum with the pivot, while light counters run in the opposite direction, as shown on the drawing. There are six points of contact between the turn-table and bridge, the middle contact being made by means of a heavy cross-girder, as shown on drawing.

The trusses of this span are placed 23 feet 6 inches apart, centre to centre, and from the depth of the permanent spans at the free ends rise in an easy curve to a depth of 12 feet 3 inches at centre. An important saving of material would have resulted from an increased central depth, but the Commissioners desired, if possible, that the trusses should not be carried so high as to necessitate horizontal connection between the top chords. It may be remarked, also, that the height adopted allowed of a curve in more pleasing proportion to the depth of the fixed spans. Owing to this arrangement, it was deemed desirable to form the top chord of weldless links, the voids between adjacent links being filled in with packing pieces, wedged in place with keys. In addition to this, the two separate lines of links on either side of posts were further stiffened laterally by means of light castings, as shown upon the drawing.

The usual riveted arrangement of a top chord for such purposes would have required a large excess of metal, for self-evident constructive reasons.

The lower chord of either truss is composed of four nine-inch channel bars, of increasing weight from end to centre. These bars are strongly braced together, and their continuity is assured by splice-plates and rivets. The posts are in pairs, as in the fixed spans, and are also wrought-iron columns.

They are placed for nine panels, 10 feet 8 inches apart, while the first panel on either side of centre post is 7 feet 6 inches long. The centre post over pivot is a single one for each truss, and is compounded from four six-inch channel bars and four segments of a cylinder, riveted together by means of their flanges. (See section.)

The diagonals are square bars, with upset screw ends bearing against angle blocks, fitting between shoulder plates riveted to under side of lower chord.

The cross girders at every other panel are single trussed beams instead

of double, as in the case of the fixed spans. The base castings of the end posts have a circular track bolted to them, composed of two six-inch channel bars, back to back. The bearing is upon wheels bolted to the masonry, and upon which the above track runs as the draw is open or shut. A self-acting, vertical latch secures the draw in position when closed for traffic, and is opened by means of a lever, operated at centre of bridge. A compound gear is arrranged on the drum in case a heavy wind is blowing, or to ease the bridge tender in starting the bridge from its bearings after a long period of quiescence.

The following data in regard to "weights" will prove of value in this connection:

First. Permanent span.

| | |
|---|---|
| Average weight of iron per foot | 620 lbs. |
| " " " timber railing | 710 " |
| | —— 1,330 lbs. |

Second. Draw span.

| | |
|---|---|
| Average weight of iron per foot | 1028 lbs. |
| " " " timber railing | 575 " |
| | —— 1,603 lbs. |
| Turn-table and appliances | 85,000 " |

In the presence of the city authorities and parties interested in this work a careful test was made by means of pig iron, with which the bridge was loaded up to one ton to the foot. Under this load the permanent spans deflected seven-sixteenths of an inch, which was recovered when the load was removed. The draw was only loaded half its length, the result being a deflection of nine-sixteenths of an inch, which was recovered before half the load had been removed. Had the draw been loaded over its *whole* length instead of half its length, with a ton to the foot, the result would have been still more satisfactory. The deflection on either side would probably have been but little over half of what was exhibited. The result of these severe tests is regarded as eminently satisfactory. Although more attention has been given to æsthetical considerations than is usual in such work, much more could have been accomplished had the expenditure been authorized. As it stands, the bridge is painted a pleasing monotone of light yellow ochre, the effect of which would have been very much heightened by picking out the mould-

ings, bolt-heads, and other salient points with an Indian or brownish red. This I trust will be done by the city authorities when the bridge requires re-painting.

It may be of interest to note the fact that *all* tension members in the main trusses were tested up to 20,000 pounds per square inch, which strain they were required to stand without a permanent set.

XXV.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

## TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

At a meeting of the Society, Feb. 15th, 1871.

## ACCIDENTS TO RAILWAY STRUCTURES.

A paper presented by Mr. THOS. C. CLARKE, C. E., Member of the Society.

Railway accidents may be roughly classified as follows:

I.—*Running off the track* from breakage of parts of engines or cars; breakage or displacement of rails; malicious or accidental obstructions on track.

II.—*Collisions* from disregard or misunderstanding of signals; overcrowding from badly arranged time-tables; misplaced switches; accident to train on one track throwing it in the way of train on the other.

III.—*Failure of structures* from decay or original bad design; shocks from breakage of machinery, causing trains to run off track while crossing, or from collisions on bridge.

It has been observed that the most disastrous accidents have resulted from an unforeseen combination of two or more of the above causes.

The late appalling accident on the Hudson River Railway is an illustration of this, as it was a combination of all three of the above principal causes.

The primary cause was the breaking of the axle under the oil-car.

According to the evidence of Mr. Toucey, Superintendent of the Railway, broken axles have been known to run 20 miles before being discovered, "the frozen ground keeping it up; in this case it evidently dropped through the bridge."

The second cause, therefore, was failure of a structure from shock caused by breakage of machinery. This threw the car from one track over upon the other, and a collision resulted, aggravated in its consequences by the presence of petroleum, and from its being upon a wooden structure, which quickly burned down.

Much severe criticism has been passed upon the Company because "the safety signal," as it is said, "lured the train to destruction."

It appears to have been overlooked that the same unhappy result would have followed if the signal-lamp had been entirely removed, when winter changed the bridge from a movable draw into a fixed structure.

Moreover, a collision would have taken place on a fixed bridge where there never was any signal, if the broken car had happened to have crossed one. In fairness to the employees of the railway, the accident should not be attributed to a disregard or misunderstanding of signals.

The combination of a broken axle, a bridge, a car laden with petroleum, and an express train coming up at the same moment, were all required to cause this truly dreadful event.

The object of the present paper is merely to consider one of these points, and to discuss the questions whether bridges, as now constructed, are sources of danger, and, if so, can the chances of accident therefrom be reduced by different forms of construction?

It is believed that there is no instance of a bridge, designed by an American civil engineer, having broken down from bad design, or insufficient material, as did the Dee bridge in England, designed by Robert Stephenson.

All the bridge accidents in this country, it is believed by the writer (and if mistaken, he hopes some member will correct the statement), have occurred either from the falling of temporary trestle work, or from weakness caused by decay, or from sudden shocks occurring when trains have run off the track. Our bridges, both of wood and iron, are safe so long as the trains remain upon the track. How many of them are absolutely safe under all circumstances? If not, how can we make them so? or at least diminish the chances of accident? This is the practical question.

It was a practice in English bridge construction introduced by Brunel, and now falling into disuse, to make the platform of a bridge in the shape of a trough, which was filled with gravel or broken stone ballast, and the ties laid in it, just as on earthworks.

The reasons given by Mr. Brunel for this, were as follows:

1. To enable the alignment and level of the rails to be maintained by the same men and with the same tools as on other parts of the line.

2. To prevent concussion when a train came upon a bridge, as there was no change in the nature of the support given the rails.

3. To prevent vibration being transmitted to the iron-work of the bridge.

4. In case of trains getting off the rails, to prevent their ploughing through the flooring.

5. To protect timber flooring from fire.

6. To provide for changes of length caused by temperature.

7. To increase dead weight on short spans so that there might be no jar from the rapidly applied load of a locomotive.

It was Brunel's belief that the cost of the extra material required to support the ballast, was more than compensated by the above advantages.

Most American engineers would say that the first object was of little consequence; that the second and third are equally well provided for by a wooden system of flooring; that to use ballast for the fifth would do more harm than good, because the timber and plank would rot unseen; the sixth can be accomplished more easily in other ways; and that the seventh had better be attained by making the iron-work heavier. The fourth, that of preventing trains ploughing through the floor, ought to be accomplished at any cost. But let us examine if there is not a better way.

The weight of the ballast itself averages about 500 lbs. per ft. run, and that of the additional parts of platform necessary to support it about 500 lbs. more. In other words, it weighs as much as the iron work of an American truss bridge of 150 feet span, or an English plate girder of 110

feet span. This great addition of dead weight has prevented its adoption here, and caused its disuse in England.

The object which it was intended to accomplish was excellent, and it is to be feared that this has been too much neglected in the rough and ready style of construction adopted in our earlier bridges at least.

If the train jumps the track while crossing, it falls through a space equal to the height of rail..... 4½ in.

" " track stringer..... .....12 "

" " cross tie..... 5½ "

22

inches in all upon the floor beams, which, in most cases, would either be broken outright by the shock, or crowded apart by the wheels of the engine, so that it would drop through the bridge.

The arrangement of platform on most iron bridges is still more dangerous, as the floor beams, though of iron, are placed in pairs together, and from 10 to 15 feet apart, so that there is nothing to prevent the engine from dropping between them if it once leaves the rails. This is shown in Figures 1 and 2 of the accompanying sketch.

There is a mode of construction shown in plan and section in Figs. 3 and 4, which is in use upon some of the Pennsylvania coal roads which is much better provided to secure safety in case of trains leaving the rails.

The track stringers are numerous, and are strong enough to resist a severe shock. The ties are made of 4 x 12 in. plank on edge placed 6 or 8 inches apart and blocked between every one, both at each end and under the rails.

It will be observed:

1. That the distance that the wheels can fall cannot exceed the height of the rail or 4½ in.

2. That the platform is broad enough to support the wheels even if the train is off the track.

3. That the ties are so close that the wheels cannot drop between them, and, being firmly blocked, cannot be crowded apart so as to leave a space through which a car or engine may fall.

In addition to this there should be heavy guard timbers, as shown, on each side, to prevent the engine striking the trusses of the bridge before

its motion is arrested. There should also be a few planks spiked together lengthwise, so as to support the track in case of an axle or wheel breaking.

If such an arrangement does not insure perfect safety, it certainly diminishes the chances of danger far below those which are inseparable from the style of construction shown in the drawing, which it is believed is the style commonly used in this country.

As the one object of bridge building is to insure the safety of what is carried across the bridge, it would seem desirable that some of the superfluous talent which fills our engineering papers and magazines with elaborate calculations upon the strength of the parts of the main trusses of bridges, none of which were ever known to fail, should be diverted to drawing the attention of railway managers to a safer construction of the floor system than now prevails.

## XXVI.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—The Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

At a meeting of the Society, March 15th, 1871.

## PROVINCETOWN DIKE.

A paper presented by Mr. JAMES B. FRANCIS, C. E., Member of the Society.

Provincetown Harbor, near the extremity of Cape Cod, is of great importance, as a harbor of refuge, to the Commerce of Massachusetts. It is nearly land-locked by dunes of sand, and it has a shallow branch, about three miles in length, called East Harbor, into which the sand from the dunes and outer beach was blown by the wind and carried by the ebb tide into Provincetown Harbor, shoaling it on the easterly side. To prevent this, the State of Massachusetts, in 1868 and 1869, built a dike across the channel connecting the two harbors.

The last seven miles of the Cape is composed exclusively of coarse sand, which has evidently been washed up by the waves and currents to the beaches and blown from them into the dunes, some of which exceed a hundred feet in height. The sand is silicious, and of a grain and sharpness eminently suitable for building purposes, and so perfectly free from earthy matter that washing it in clear water scarcely discolors the water. From a boring, and the general depth of water in the neighborhood, it has been inferred that sand of nearly uniform character, with some admixture

of shells, extends to a depth of between one and two hundred feet below high water mark.

The site selected for the dike, is a point in the channel between the two harbors, where it is about 1100 feet wide at high water. At low water this channel was nearly dry, the bed being sand of exactly the same quality as the neighboring dunes. The velocity of the current through this channel, during parts of every ordinary flood tide, was about two and a half feet per second, and during parts of the ebb tide, three feet per second, which being much above that required to act on sand, caused a constant movement of this material, backward and forward with every tide. In a high course of tides the velocities were considerably greater.

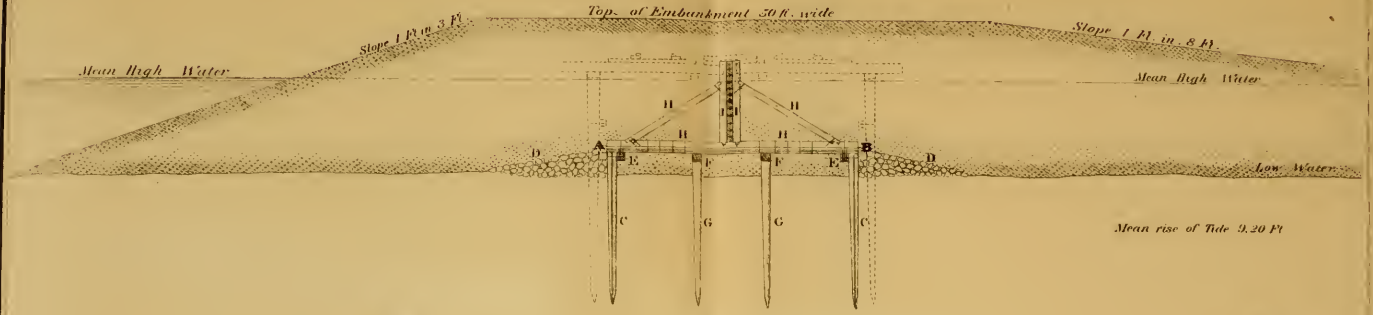
The area of the flats and marshes of East Harbor is about nine hundred acres, covered, in high tides, with water flowing through the channel to a depth varying from a few inches to about eight feet; the mean rise of tide in Provincetown Harbor being about nine feet.

The only material in the neighborhood, available for the construction of the dike, was sand from the dunes; but it was obviously useless to attempt to form the dike by a simple embankment of this material, filled in the usual manner from the shores, for as soon as the channel was contracted to a certain extent, no further progress could be made, as the current at each tide would carry away all the material put in since the preceding tide, or scour out the bottom to an equal amount. To meet this difficulty, before the main part of the embankment was formed, the channel was closed by a timber dam. In arranging for this it was necessary to provide for the ebb and flow of the tide through the channel, up to the time of closing, by some means that would not cause the bottom to scour. The plan adopted is represented in the accompanying sketch.

C, D, E, F, Fig. 1, and A, B, Fig. 2, are a plan and vertical section of a timber apron, six hundred feet long and twenty-five feet wide, on which the dam was erected. The water was prevented from passing under the apron by the sheet pilings, C, C, Fig. 2, and around the ends by the timber abutments, G, G, Fig. 1, which were connected with the shores by sheet pilings, H, H, and embankments of sand. The flow of the tide through the channel was then confined to the space between the abutments and above the apron. This reduced the section of the channel to about one-half its original area and the velocity of the current at this point was, of course, about doubled. To prevent the scouring of the bottom of the channel, to a dangerous extent, on each side of the apron, it was rip-rapped

Fig. 2.

SECTION AT A=B Scale $\frac{1}{16}$ 1 foot



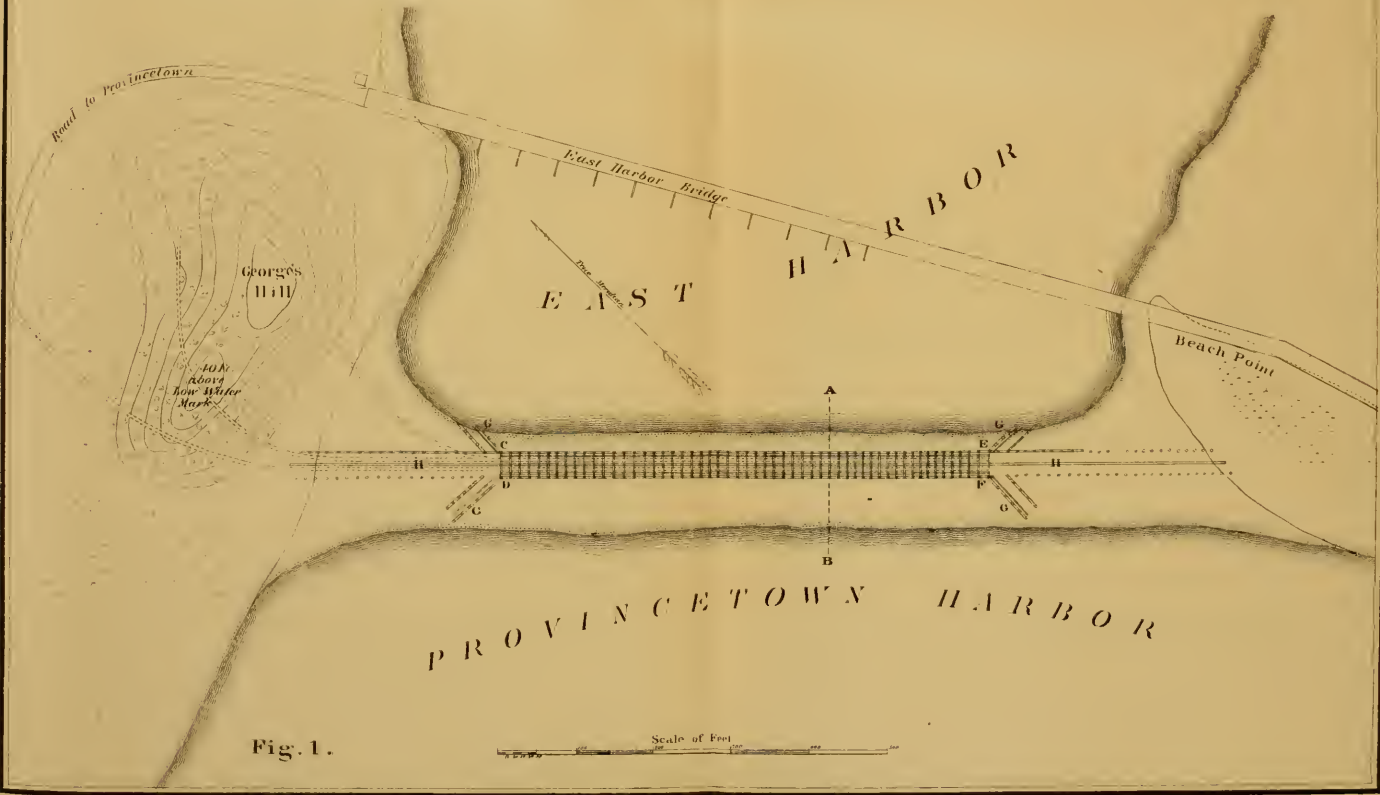




Fig. 1.

Scale of Feet

for a distance of about twelve feet on each side, as represented at D, D, Fig. 2. The sheet piling was driven from a staging represented by dotted lines in Fig. 2; it was driven into the sand bottom to a depth of about twelve feet, and cut off at low water at about two feet above the bottom.

It was necessary to drive the sheet piles, before the rip-rap in their immediate vicinity was put in, otherwise the stone would have interfered with the driving. To protect the bottom from scour in the neighborhood of the piles as they were being driven, it was covered with sand bags, which offered no obstruction to driving.

To close the channel, frames H, H, Fig. 2, were erected on the apron, ten feet apart, to support the vertical planking, which was dropped in between the posts I, I, when the channel was finally closed, Nov. 4, 1868. An embankment of sand from the neighboring dunes was then made with the apron, dam, etc., buried in its centre, which forms the permanent dike.

The porous character of the sand allows the pressure of water to be communicated through it for considerable distances; the effect of this was shown at a small freshwater pool in the neighborhood, about three hundred feet from high water mark. At high water, or soon after, the water covered an area of several hundred square feet, the greatest depth being about two feet. At low water the pool was entirely dry, the water appearing and disappearing regularly with every tide.

The water shut in by the dike is now brackish and has an area of about two hundred and fifty acres, and has assumed a level near half-tide. Ordinarily there are no freshwater streams or springs flowing into it. At high water there is a considerable percolation into it through Beach Point, the long, narrow strip of sand, a few feet above high water, separating it from Provincetown Harbor; the salt water showing itself in numerous little rills on the flats, which disappear at low tide. From the permanence of the level of the surface of the water shut in, it is obvious that there must be an equal amount percolating out at low tide.

From the porous character of the sand, fears were entertained that on closing the channel, the quantity of water percolating through it under the sheet pilings, would be so great as to carry the sand with it, or perhaps give it such a semi-fluid character, that the apron and its pilings would yield to the pressure. That some such effect was not produced is probably due to the homogeneousness of the sand, which allowed the water percolating through it to be diffused through a large mass. Two or three instances

have come to my knowledge in other localities, where sand resembling this in quality, but in thin layers, confined between impervious strata, has been carried out by the percolation of water, under pressure, allowing the superincumbent strata to settle. In these cases the mischief was attributed to the concentration of the action of the water on a small body of sand; if the adjoining strata for a considerable thickness had been equally pervious to water, there would have been no such concentration, and there was reason to think that the sand would not have been carried out.

## XXVII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

At the Second Annual Convention of the Society, June 15th, 1870.

## WAVES OF TRANSLATION IN FRESH WATER.

A paper read by HON. WM. J. MCALPINE, C. E., Member of the Society.

An exceedingly interesting case has been lately heard and decided by the Board of Canal Appraisers of the State of New York, the solution of which, hinged entirely upon engineering testimony, and is the more interesting to the profession, inasmuch as the counsel upon both sides had as associates, civil engineers, who really conducted all that part of the case, in which professional questions were involved.

On the part of the State and defense, was the legal counsellor, Charles Rhodes, who was also an hydraulic engineer, and was assisted by Professor D. M. Greene, a member of the American Society of Civil Engineers, and Mr. L. L. Nichols, C. E.

On the part of the claimants, were Wm. J. McAlpine, late President of the Society, Charles H. Haswell, a member thereof, and Samuel McElroy, C. E.

The general outlines of the case were as follows:

On the 21st of April, 1869, an earthen embankment, which had been built in 1856, at the headwaters of the Black River, by the State, to form a retaining reservoir, for supplying water to the Black River Canal, in the dry seasons, gave way, and precipitated three thousand millions of gallons of water into the

river, and flowing down carried away several large mill-dams, the waters of which increased the flood wave from the reservoir, until it reached Lyons Falls, where these accumulated waters fell nearly perpendicularly 53 feet into, what has been termed "the pool" of the Black River.

This "pool" is a flat portion of the river, forty miles long, between Lyons Falls and Carthage, with an hydraulic slope of 5 feet in low water, and at this time (when the river was swollen by a heavy freshet,) with a slope of 15 feet.

The reservoir wave, in passing over the dam above Lyons Falls, was claimed to be about four thousand millions of gallons, and was ten hours in passing over this dam, from the front to the rear end of the wave. About two-thirds of the increased volume of the water (that is, of the reservoir wave strictly,) passed over the dam in five hours

From the testimony in the case and the calculations of the rate of flow of the water, no considerable portion of the reservoir wave water reached the lower end of the "pool" at Carthage in less than six hours.

A portion of the State dam at Carthage, forty miles below Lyons Falls, gave way about two hours after the reservoir water began to plunge into the pool at Lyons Falls, and the claimants alleged that the additional waters of the pool, liberated by the breakage of the dam, flowed down the river and caused the great devastation, which was produced for twenty miles below Carthage, particularly at Watertown.

For the damages at and below Carthage, the State Appraisers awarded to the claimants about $300,000, on the ground that the breakage of the Carthage dam and the release of the waters of the pool, and the "displacement wave" at Carthage, produced by the plunge of from one to two hundred tons additional per minute, falling fifty-three feet, was the measure and effect of the reservoir water.

The seeming paradox in this case is, that the reservoir water should have produced these effects, at and below the Carthage dam, four hours before the water itself did reach the dam.

The claimants alleged that an unusual and extraordinary rise of water occurred at the Carthage dam, about two hours after the reservoir wave in volume began to plunge over Lyons Falls.

The defendants alleged that whatever this rise was, it was due to the flood waters from the large tributaries of the Black River below Lyons Falls, and that it was impossible for the reservoir water to effect a displacement swell, though the winding channel of the pool, and its enlargements to three miles wide in some places, and in others to contractions of only a thousand feet, and where the channel constantly varied greatly in depth, and that the momentum of the water falling fifty-three feet, was nearly destroyed at or near the falls, and could not have extended more than a few miles below, and would be insensible at the dam at Carthage.

Mr. McElroy was a leading witness on the part of the claimants, and he brought forward in support of his views the theory of the wave of translation,

as enunciated in 1837, and subsequently by J. Scott Russell, C. E., of London. This theory is given at length in Beadmore's Hydrology, page 207.

J. Scott Russell says of "the primary wave," "That the velocity of this wave in channels of uniform depth is independent of the breadth of the fluid, and equal to the velocity acquired by a heavy body, falling freely by gravity through a height, equal to half the depth of the fluid, reckoned from the top of the wave to the bottom of the channel.

"That the velocity of this primary wave is not affected by the velocity of impulse, with which the wave has been originally generated, neither do its form or velocity appear to be derived in any way from the generating body.

"The great waves of translation are reflected from surfaces at right angles to the direction of their motion, without suffering any change but that of direction.

"The great primary waves of translation cross each other without change of any kind."

The following table was prepared from very careful experiments at ten stations, on thirty-eight miles of the tide wave of the Clyde:

TABLE.

| MEAN DEPTH. FEET. | VELOCITIES MILES PER HOUR. | | DISTANCE, MILES. |
|---|---|---|---|
| | CALCULATED. | MEASURED. | |
| 240 to 360 | 60 to 80 | 80 | 20 |
| 25 | 19.3 | 20 | 8 |
| 5 | 8.6 | 8.1 | 5 |
| 15 | 14.9 | 15 | 5½ |

Mr. Haswell also stated, that his wave of translation was illustrated, by the tidal wave of the Hudson river, which in a flood, flows up to Albany 170 miles in 15 hours, against an actual fresh water current of an average of two miles an hour, and while the wave proceeds forward without reference to the expansions and contractions of the channel, bodies floating upon the surface of the river are actually flowing against the wave, and no salt water whatever passes above Poughkeepsie.

This illustration is the more remarkable as the Ocean wave, which gives motion to the Hudson River wave, moves from east to west, while the latter moves exactly at right angles to it, viz., from south to north.

Mr. McAlpine expressed his views on this wave of translation substantially according to the Russell theory, stating that in this case, each particle or particular quantity of the volume of the reservoir water, as it plunged over the falls at Lyons, produced a percussive effect on the water in the pool, which was measured by its weight into its velocity, or, in other works, its momentum.

That this *effect* was distributed, first, in the recoil of the water impinged upon against the rocky sides and upper end of the pool immediately at the fall, and next, in producing an increased current in the water then in the pool, and the residue of this vast developed force, which could not be immediately absorbed in the movements above alluded to, in the transmission of a wave of force in the direction of the line of least resistance, viz., in that of the already flowing waters down stream, produced by the freshet or flow of water in its regular channel towards the Carthage dam.

The loss of force of this immense volume of the reservoir water on the sides and upper end of the pool, at the foot of the falls, was inconsiderable, perhaps in all (including some losses not before spoken of,) it may have amounted to ten per cent., and this remainder of the amount of developed force, was directed against the water in the pool, first, to produce a pressure against it, as in a closed pipe, and subsequently in an elevation of the water at the pool, equal to the hydrostatic head required to deliver the additional volume of the reservoir water, in its ordinary way in the river channel.

In this case the Russell law of the tidal wave of translation, which produces but one act of propulsion, becomes a constant force, under the continued deliveries of the reservoir water, and a succession of waves of translation ensue, each of which overlap the preceding ones until they become a slope of translation, extending from the pool below Lyons Falls, to the dam at Carthage.

The important point in this case was to determine whether this wave of translation was not obliterated by the configuration of the river below Lyon's Falls, in consequence of the extreme changes of the depth and width of the river channel between these points.

To illustrate this subject he stated that if in a close pipe of considerable length, being already filled with clear water, a small quantity of colored water was poured in at one end, *almost* immediately an equal quantity of the clear water would be discharged at the other end, and, if this experiment was continued, the colored water poured in would not discharge at the lower end of the pipe *until all of the clear water* was forced out of the tube.

Following this was a statement that if the top of this tube was removed and the sides carried up, so as to prevent any splashing over, *nearly* the same effects would be produced, viz.:

That the effect of pouring in colored water at the upper end of the open pipes would *in all cases* be to almost immediately displace exactly the same amount of clear water at the lower end of the open tube, long before any of the colored water could reach the lower end.

To demonstrate this proposition ocularly, Mr. McAlpine constructed a wooden box, eight feet long, six inches wide, with sides a foot in height, and at the lower end placed a block which extended four inches above the bottom.

He tried various experiments with this box in the presence of the Board and of the counsel on both sides and of the Engineering witnesses.

On the first trial red-colored water was poured into the box (already full of white water), and in two and a quarter seconds the white water already in the

box was discharged in successive waves; and in each case the white water discharged at the lower end of the box channel *was exactly equal* to the quantity of red water which was poured in at the upper end.

This red-water was subsequently poured in at the upper end in quantities as nearly equal as possible, and continuous, when the stream of white water was delivered in just two and a quarter seconds after the plunge was made, although the actual red water was in this case four minutes in passing down in the channel of the stream; that is, that the "wave of translation preceded the wave of motion as $\frac{2}{4}:\frac{2}{60}$, or as one to 0.09."

As the case had to be argued before a Court not skilled in engineering questions, and in the presence of adroit counsel, it was necessary to present the experiment as nearly as possible under the same circumstances as those in the river; that is, with the channel alternately contracted and expanded, and curved and deflected, and with its depth increased and decreased.

For this purpose he had a number of tapering blocks made, which were nailed to the bottom of the box on the inside, which reduced the depth one-half in a number of places, and similar blocks nailed on each side of the channel, which reduced the width at those places to one-third and two-thirds, and rendered the channel quite crooked. After these obstructions had been put in, the experiment was repeated, and in two and a quarter seconds after the colored water was poured in, at the upper end, clear water in equal quantities flowed out at the lower end.

This showed conclusively that these obstructions produced but *little* effect upon the velocity of the wave of translation.

It has been said that there was but *little* effect upon the velocity. The experiment showed no effect; but it was considered that there was probably some slight decrease in the velocity, which it was at that time impossible to measure accurately. In the next experiment, the red water was poured into the upper end of the box in a continuous stream of the same magnitude as before, and the translation wave again passed through the box in two and a quarter seconds; but the red water itself was six minutes in passing to the lower end, or $\frac{2}{6}:\frac{2}{360}$, one to 0.006.

This experiment showed that while these numerous obstructions produced but little effect in reducing the velocity of the wave of translation, they did reduce the velocity of the wave of motion one-third.

Mr. McAlpine gave his testimony before the Court on the 24th and 28th of December, and ten days afterwards received the annexed letter from J. Scott Russell, which coincides so completely with his evidence as to almost suggest that he had had some previous correspondence with Mr. Russell.

This, however, was not so, and the testimony and letter of Mr. Russell are the more valuable for their coincidence:

PARIS, December 16, 1869.

*To Messrs. McAlpine, McElroy, and Nichols, Civil Engineers, New York State:*

GENTLEMEN—I am requested by Mr. Farwell to communicate to you the results of my examination of the circumstances and facts of the floods on the Black River in last April.

I learn the facts to be as follows:

(1). The waters from the reservoir reached Lyon's Falls about 11 o'clock P. M. of Wednesday.

(2). Lyon's Falls are distant from Carthage Dam about thirty miles on the straight, and thirty-five on the windings.

(3). The Black River was already swelled and its channel filled with the waters of its tributaries, and the low lands adjacent were flooded.

(4). In these circumstances the waters at the Falls was thirty feet deep, and at Carthage fifteen feet deep.

(5). The mass of water discharged from the reservoir was over 400,000,000 cubic feet.

(6). The mass of water from the reservoir raised the river above the Lyon's Falls some six feet.

From these facts I draw the following conclusions:

(7). That the time at which the effects of the flood from the reservoir would be felt at Carthage Dam is about two hours later than at the Falls.

(8). That the flood wave would travel at about the rate of sixteen miles an hour.

(9). That the flood shallows would somewhat diminish the speed of the wave, but that the speed of the stream would increase the speed of the wave.

(10). That the curves in the channel would not diminish the speed of the wave. They would diminish its rise somewhat.

(11). That if the flood wave was at Lyon's Falls at 11 P. M. Wednesday, it would be at Carthage Dam about 1 in the morning. And if it made the highest mark at the Falls about 3 in the morning of Thursday, it would make the highest mark at Carthage at somewhat earlier than 5, owing to the increased depth.

(12). That the actual flood water out of the reservoir might not reach Carthage till some hours after the wave; that is, not until the speed of the running stream carried down the water. The consequences of the wave would last much longer and travel much slower than the wave itself.

I have the honor to be, gentlemen,

Very sincerely and respectfully yours,

J. Scott Russell.

P. S.—The phenomenon of the flood wave can be easily shown on a model. Take a trough of wood a foot wide and a foot deep, thirty feet long. Fill it with six inches of water; let the far end of the trough be cut down to the level of the water; suddenly tumble a bucket of water in at the near end. In a few seconds a bucket of water will fall over the far end. Make a trough with the curves in it; you will find no important change.

I regret I cannot send you my book with the information you want. My early experiments, which are accurate, are in a report of the British Association for the Advancement of Science (1844), and were never published separately. You will find these volumes in every scientific library. My subsequent observations are not published.

A few weeks afterwards, the author met a party of engineers at Boston, to whom he presented this case, and found that they were perfectly familiar with the principles of the wave of translation, and had made numerous experiments on the Merrimac and Concord rivers, which completely demonstrated the law.

At Lowell, the hydraulic canal abstracts from the Merrimac River a large volume of its waters. This water, passing over or through the wheels, is returned to the river, below the dam, through the tail races flowing into the pool with velocity, but with no percussive effect.

The dam is sixteen feet high, and the residue of the water not drawn through the canal flows over this dam also into the pool below.

At Lawrence, thirteen miles below, on the same river, there is a similar hydraulic canal and dam. The river is crooked, of varying widths and depths, and a rapid in one place, with one footfall in a hundred yards.

The mills at both places are generally run day and night through the week; but on Saturday night, about 8 o'clock, they are stopped until Monday morning,

The gates of the hydraulic canal are closed at this hour, and it is immediately telegraphed to Lawrence. The effect of closing the gates is to cause a rise of the river water of about two feet upon the dam at Lowell, and in fifteen minutes from that time, a similar rise of about eighteen inches takes place upon the dam at Lawrence. Floats have been repeatedly put in the river, just below the dam at Lowell, and they occupied twelve hours or more in floating down the river (thirteen miles) to Lawrence.

This case is the more remarkable because the same quantity of water flows through the river between Lowell and Lawrence for the whole week, the only difference being that, on week days, a considerable portion flows around the dam, and enters the pool below without percussion; and on Saturday night, this portion of the water is added to that which passes over the dam, and by its increased percussion, due to the fall of sixteen feet, produces a wave of translation, which moves thirteen miles in fifteen minutes, and raises the water on the lower dam eighteen inches.

At Manchester, on the same river, there is a similar hydraulic canal. When the gates of this canal are shut, the percussive effect of the water flowing over the dam produces a wave of translation, which passes down the river to Lowell (thirty miles) in ninety minutes, and fifteen to twenty hours ahead of the flood wave.

These Lowell experiments are so pertinent to this Black River flood case as to settle the question whenever it shall again come before the courts.

Mr. Russell states that he has been engaged in two suits at law where this principle was involved, and that some of the best informed engineers of Great Britain were introduced as witnesses, all of whom agreed in regard to the effects of this wave of translation.

I have dwelt longer upon this part of the subject because the unprofessional flippant writers in the local newspapers have ridiculed the theory, and perhaps given a tendency of public opinion against its correctness and applicability to the case in hand.

The application of this law is new in American engineering practice, but there are many cases where it becomes necessary to consider it.

A primary question in this case was to determine whether the failure of the reservoir embankment was due to the imperfect construction and management, and consequently whether the State was liable to the damages which its breakage caused. The remainder of this paper will be devoted to this question,

The drainage area of the reservoir was nearly seventy square miles, with rapid side slopes to the stream, of three hundred feet descent in two or three miles of distance.

The reservoir was about three miles long, covering over four hundred acres, with a depth of thirty feet at the lower end. The top of the embankment was four feet above the ordinary flow line, and the pond contained at this level three hundred thousand cubic feet of water, and when filled to the level of the top of the bank, as it was at the time of the break, it contained nearly four hundred thousand cubic feet of water.

The banks were made of earth, ten feet wide on top, with inside slopes of three to one, and outside of two to one. Through the middle of the bank there was built a vertical line of sheet piling from the bottom to one foot above the flow line, and in front of this was a sort of concrete wall, one foot wide at the base, and half a foot at the top. In front and rear of these were earthen puddled walls. The water slope was covered with a rip-rap paving. At the foot of the bank, on the lower side, was a crib of timber and stone, six and a half feet wide and nine feet high.

Through the dam was carried four wooden culverts, each of three feet ten inches square, with cast-iron pivot gates in the middle of the dam, of four feet by two feet six inches, which were operated from the top of the bank through a perpendicular well, built of wood. The original spill was forty feet long, and eight feet below the level of the top bank. But in 1861 a plank dam was put in this spill way, which filled it up four feet, or to the level of the flow line. Near the middle, the top of the embankment had, in the course of years, settled a few inches lower than elsewhere.

The law under which the damages caused by the break of this dam were to be adjudicated, required the Courts to first determine the responsibility of the State in regard thereto, and hence came up the two questions: 1st, Whether the reservoir had been constructed properly; and 2d, Whether it had been managed carefully and judiciously.

Banks and dams, to retain water, are usually made of stone, wood, or earth. When the two former are used, they are arranged to discharge water over them, and are regarded as safe, when they are built of durable materials, made water tight, and prevented from undermining, especially on the lower side.

When earth banks are used, no water must be permitted to pass over them, and special passages must be provided for the waste water, which are usually made of stone or wood, and located so far from the earth work of the dam, as to avoid any danger thereto in the passage of the water.

They also require a protection on the water slope to prevent its abrasion. The spill ways should always be self-acting, and of sufficient capacity to discharge the greatest floods which can possibly accumulate in the reservoir, without rising within two or three feet of the top of the earth bank; and they should be so located as not to be liable to become obstructed by drifting timber, trees, or ice. The banks must be rendered perfectly water tight within

themselves, and particularly in their connections with the natural grounds on the bottom and sides of the ravine.

The first of these objects is accomplished by a puddle wall, made of as pure clay as can be procured, and mixed with fine gravel, in nearly equal proportions, and moistened and compacted together with spades over each layer of six inches—in fact, to make an artificial hard pan. The second object requires the utmost care, for it is far easier to make an artificial bank water tight than it is to prevent the escape of the water between it and the natural soil, even when the latter is itself water tight. Unless great care is taken, the water will percolate between the new bank and the natural soil, at first, in exceedingly small quantities, but increasing in time, until leaks of considerable magnitude will occur, and frequently to such an extent as to carry away the bank. The porous earth in the bottom and on the sides of the valley should be removed for at least the width of the front half of the bank, and the material thus excavated may generally be deposited so as to form the rear portion of the bank.

The next step is even more important. The puddle wall should be sunk into the natural good earth, from three to six feet below the other part of the bank, and this not by one trench, but by two or more, each to be of different depths, making what is called "a toothing."

The puddle wall should be carried into the hill sides, in the same manner, but with horizontally as well as vertical toothing; and here, it may be remarked, that the bottom of the puddle wall must be level in both directions, and never inclined. All changes of level should be made by vertical steps.

It is also a good plan to build the front half of the bank with its base as nearly level transversely as possible; and this does not necessarily involve a large expense, as the vertical steps may be made as frequent as desired, and thus require the removal of only a small quantity of material. The aim of the engineer should be to make the puddle wall and a small section of the bank in the rear, and a larger one in the front, impermeable to the percolation of water. When this is done, he should bear in mind that the remainder of the bank, especially the rear, is put in merely to give stability and permanence to the water-tight portion.

On one occasion, I found an assistant requiring the contractor to cart all of the stone from the excavation into spoil bank, and to make the rear as well as the front portion of the embankment entirely of earth, because the contract had been written requiring the front portion to be made in that manner, and nothing had been written about the manner of building the rear portion.

These stone, compactly laid, were precisely what were required for the rear part of the bank.

The Black River dam was built in the wilderness, and the engineer in charge was unable to visit it very often. There was, therefore, no assurance that it had been constructed with the same care that characterizes the other State works.

Nevertheless, there was an inherent element of destruction in the plan of the dam.

It was only half as wide on top as it should have been, and the spill way, as changed, was insufficient, and liable to be obstructed; but, worse than all, was the introduction of sheet piling or planking through the dam.

In the first place, these were of sawed plank, and battened with boards, and such planking will not prevent the leakage of water under even two feet head, and were, therefore, useless against such leakage, but they were also very detrimental.

The engineer can never be assured that the contractor and his workmen will perform all of his work perfectly. There is always the liability of some small leaks. If any portion of the front part of the bank permits of permeation as far as the sheet piling, the water will readily pass through the latter, and follow it lengthwise of the bank until it finds an escape through the latter, and then, by gradual wearing, enlarge the orifice sufficient to produce a breach.

It may here be remarked, that water will follow along a smooth surface an almost indefinite distance. I have seen more than one break occur on the canals from a run plank left in when the bank was built.

I have another old canal hint to give to young engineers. When a leak is discovered, as long as the water runs clear, there is no danger—it is only the loss of so much water. When the water runs out muddy, then the danger begins.

Yet every prudent engineer watches even clear running leaks very closely. It may at any time change to muddy water, and produce a break in a few days, perhaps hours.

The concrete wall in the Black River bank was altogether too narrow to be of any service. It may have led the superintendent and the contractor to trust to it, and to have taken less pains with the puddle wall.

The latter, if well built, and of sufficient size, and well connected at the bottom and ends, would have been sufficient to render the dam perfectly tight.

No person was present when the dam ruptured, and therefore it is impossible to determine how it occurred. From a careful examination of all of the accounts given in the testimony, of the shape and size of the breach, and of the flood wave which it produced down the stream, it would appear that the spill way had been partially choked up with logs; that the melting of the snow and a gentle warm rain had thrown a considerable quantity of water into the pond, which could not escape through the spill way, and partly open waste gates, and thus the water gradually rose to near the level of the top of the reservoir bank, and finding a passage over a depression of a few inches (say six), and ten or a dozen feet wide, it slowly wore off the soft, unfrozen earth, producing a channel of gradually increasing depth and width, and running down the rear slope of softened earth of the embankment, soon removed the rear support of the sheet piling. The vast body of water in the reservoir maintaining the volume of the breaching stream until at last so much of the rear support of the sheet piling was removed, that it toppled over, and allowed the reservoir water to rush out in frightful volume, and plunging down, to

rapidly tear out the earth and outwork to and below the original base of the dam.

I have made a calculation upon the above basis, and certain rates of the enlargement of the breach, and found that the main body of the waters collected in the reservoir would have passed out in about ten hours, though it probably rushed out in two great volumes when each section of the sheet piling gave way.

The testimony in regard to the flood wave passing down the river, corroborates this theory of the rupture, or rather this theory has been prepared to meet the testimony.

As stated in a previous paper published by this Society, I have availed myself of this interesting case to lay before our junior members some further hints and suggestions in regard to the practical questions which they will be likely to meet in their future experience.

XXVIII.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

## THIRD ANNUAL CONVENTION.

The Third Annual Convention of the AMERICAN SOCIETY OF CIVIL ENGINEERS was held on the 21st of June, 1871, in the rooms of the Chamber of Commerce, corner of Cedar and Chambers St.

The President, ALFRED W. CRAVEN, Esq., being absent on the Pacific coast, the Vice-President, Colonel JULIUS W. ADAMS presided. A. P. BOLLER, Secretary.

Col. ADAMS opened the meeting with an address of welcome.

WILLIAM ARTHUR, Esq., as representative of the Committee of Arrangements, made a report which was duly accepted.

The Secretary then read the following paper from T. W. Pratt, on Trusses and Trussed Arches.

## SOME OBSERVATIONS ON TRUSSES AND TRUSSED ARCHES.

A paper presented by T. Willis Pratt, C. E., Fellow of the Society.

A Truss may be defined to be, a mechanical mode of strengthening a beam or arch, which sustains a load over any open space; it being understood, that the points of support of the ends of the beam or arch, simply sustain the weight of the structure. Trussing is accomplished by means of braces placed in an oblique direction, and thus transferring points of support from the middle of a beam or arch to the abutments. Braces are of two kinds, viz: those which resist by compression, and those which resist by tension, and this circumstance determines that there are three principles in trussing. *First.* Where the oblique braces are in compression, and the vertical supports in tension. *Second.* Where the oblique braces are in tension, and the vertical supports in compression. *Third.* The triangular truss, in which there are no verticals, but both kinds of braces are oblique in position, forming a series of triangles. All these three modes of trussing without arches, were used by the writer of this paper on the Providence and Worcester Railroad in the year 1846.

What we require is the most economical method of using material to resist force. Material is dormant. Force is active. All forces act or produce effect in straight lines. Solid material resists force best when presented against such force in a straight line, as in a post sustaining a weight. It is known to be true, that a straight vertical post will sustain more weight, placed so as to press directly down the center of the material of the post, than a post of equal size and quality would sustain, if crooked or placed in an angular direction. Again, a post, the length of which is greater than a certain ratio to its diameter, will sustain less weight, than if shorter than said ratio. This is not the case with material sustaining weight by tensile resistance, for within practical limits, the strength of said material is the same, whether long or short. Therefore in disposing

of material in a truss, all those parts which resist force by compression, should be placed on the shortest lines, and those which resist by tension, should be placed on the longest lines. These observations condemn the theory, belief, or common notion, that arches or arched trusses are stronger than rectangular-paneled or triangular trusses. Arches must be weakest, from the fact that the arc or compressed member is longer than the chord or tie, which is the tensile member ; also from the fact that the arch in compression is curved, and the tie is straight. It is a common and vague idea, that there is immense strength in an arch, but we know that the resistance is in the material, and not in the form of the arch.

Material, wherever and however placed, will fail, if loaded beyond its elastic limit, per unit of surface. We believe it to be more difficult to get an equable pressure upon the area of cross-section of an arch, than upon the area of cross-section of the straight chords of a truss-bridge. Unequal pressure involves excess of pressure, and consequent failure. The attachment of braces to an arch at intervals, throws the strain upon particular points of the arc, from which the strain is conducted in a straight line to the foot of the arc, which straight line does not pass centrally through solid material. View the whole subject as we may, in all its details, and we are brought more decidedly to the conclusion, that the simple truss without an arch, is the most economical structure. The same observations apply, in reference to the camber of a truss ; no more camber should be allowed than the amount of deflection of the truss, under the action of its maximum load. Some engineers have sought to economise material in a trussed arch, by reducing the quantity at the crown, according to a theoretical calculation, which shows that the pressure caused by a passive uniform weight, is less at the crown than at the foot of the arc. This practice can be suitable, only to solid arches in masonry, where the pressure is not concentrated at special points, but more uniformly distributed, and where we have the whole width of the roadway and arch in solid matter, to give lateral stiffness. But where an arch is built up on each side of a road, (thrown over as it were through the air,) and not absolutely supported laterally, it seems clear that the arch should be largest at the crown. It is the bow and string form, and stiffness is obtained by enlarging the bow in the middle. Indeed the bow may be considered as a post, with counteracting pressures at each end, and when the length exceeds a certain ratio of the thickness, the post will require enlargement at the middle, unless

absolute support can be obtained laterally, which is not often the case. No doubt many cases can be cited of arches in wood, combined with trusses, which have stood a very long time, and we believe that investigation would develop the fact of an excess of material, so that the pressure from loads, per unit of surface, is much below the destructive limit. In the present age, there exists great temptation for cheap talent to scheme for important positions, and the limit of safety is often passed. Many new plans are devised, and struts, tie-rods, arches, chords, counter-braces, &c., are often arranged in web-like frames, in the most intricate confusion. Merit is often claimed for an absurd departure from absolute principle.

Can the American Society of Civil Engineers use their authority, to determine the standard pressure, per unit of surface, for the various kinds of building material, and also the standard load per square foot, or per linear foot, for bridges ? A question for discussion. At present I think they cannot.

A pamphlet by Mr. S. T. Abert, was then read ; subject, Ship Basin and Graving Dock at Pensacola.

Mr. J. Dutton Steele then read a very interesting article on Nesquehoning Tunnel, in connection with which he exhibited a number of rock specimens.

XXIX.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

AT THE THIRD ANNUAL CONVENTION OF THE SOCIETY, JUNE 21ST, 1871.

## NESQUEHONING TUNNEL.

A paper read by J. DUTTON STEELE, C. E., Member of the Society.

Nesquehoning Tunnel, in Carbon County, Pennsylvania, is a work of the Lehigh Coal and Navigation Company. It pierces Locust Mountain, and will connect their railroad in Nesquehoning Valley with their extensive coal operations in the valley of Panther Creek. At present this coal finds its way to market by that interesting system of inclined planes and gravity roads known as the "Switch-backs of Mauch Chunk," which has commanded the admiration of travelers for more than forty years, not only on account of the beautiful scenery which its route displays, but also from its early and admirable adaptation to the purpose for which it was

designed. It has, however, become worked up to its capacity, and in arranging to extend their coal mining operations, the company have wisely determined to avail themselves of the locomotive, which has had its practical development since they were the pioneers in railway enterprise.

It passes through the base of the mountain at an elevation of some fifteen feet above the water on either side, and five hundred and fifty-four feet below the crest, and cuts the strata at right angles, where they have a south dip of about forty-five degrees. Its length is thirty-eight hundred feet, of which thirteen hundred feet are through the coal-measures, with all their various strata of coal, coal-shale, sandstone, and conglomerate, twelve hundred feet through the conglomerate formation, with its occasional strata of coal-slates and sandstone, one thousand feet through the red shale, with occasional strata of sandstone, and three hundred feet at the north end through the debris, and soft and decomposed red shale, which is found overlaying the red shale formation. It has encountered in its progress as hard and as soft material as is often met with in tunnelling.

After mature investigation it was determined to use the Burleigh Drills, driven by compressed air. With the advantage of the experience at Mont Cenis and Hoosac before us, we should, and it is believed we have obtained better results, as to cost and progress, than attended either of those works in their early stages, and I may here state that I believe no other known process is capable of penetrating this conglomerate formation, with that economy and rapidity which is necessary to meet the present demands of capital. This whole work has been done with six of the "two-drill" compressors, made at Fitchburg, Mass., and with sixteen drill engines, and we have averaged as much as one-half of the drill engines constantly in operation, and sometimes two-thirds.

The explosive used was gunpowder, ignited by the electric spark, but the requirements of ventilation, and the hardness of the rock, demanded powder of the highest government standard. Some doubt which existed as to the economy in the use of the more powerful explosives, when the cost of drilling was reduced by machinery, and their greater danger, with the existing knowledge of workmen of their use, caused them to be rejected, and the result in the freedom from serious accident has been satisfactory, as we have not, thus far, lost a life from premature explosions.

American steel has been used ; several of our own makers produce a better and cheaper article for the purpose than can be obtained from

abroad, and the best we have had is from the William Butcher Steel Works at Philadelphia.

The headings are driven at the bottom, eight feet high by sixteen feet wide, and where arching is required, the full width for a double track is taken out, that the tunnel may hereafter be enlarged, without disturbing the arches. At this date, both headings are in the red shale, and about five hundred feet apart; they will be joined in August, and, until the tunnel is finished, full details of the work cannot be given; but the accompanying statement of Thos. C. Steele, chief assistant-engineer of the operations at the south end, up to June 1st, may be of some interest.

The heading to which this tabular statement refers, has been twelve months in the conglomerate, and two months in the red shale; the progress in the conglomerate has been about one hundred feet per full month's work, and in the red shale one hundred and sixty feet. The holes drilled per cubic yard of rock removed, have been in the conglomerate about eleven feet, and in the red shale about six-and-a-half feet. The powder used per cubic yard has been in the conglomerate about six pounds, and in the red shale about three-and-a-half pounds, though a bad lot of powder ran the consumption in the conglomerate up to seven-and-a-half pounds for two months.

The operation in the enlargement to which the statement refers, has been eight months in the coal measures, and two months in the conglomerate; its average monthly progress has been one hundred and sixty-six feet; its average holes drilled, per cubic yard of rock removed, three-and-three-tenths ($3\ ^{3}/_{10}$) feet; and its average powder used, two-and-seven-tenths ($2\ ^{7}/_{10}$) pounds per cubic yard.

In this enlargement a portion of hand-drilling is included, which extended over the operations of one month, and it increased both the holes drilled, and the powder consumed, showing that men do not use better judgment in directing hand than machine drilling. The Mammoth Coal Vein in this region is fifty feet in thickness, and where it was cut by the tunnel, it was crushed, or to use a miner's expression, it was "in fault," and great care was necessary to prevent a "run," or to be more explicit, to prevent this crushed coal from running into the tunnel, its inclination being forty-five degrees. If a run had started, it would probably have extended to the outcrop, a height of four hundred feet. The plan marked No. 1 will show the mode of propping. The galleries A and B, were first driven, and the masonry abutments built in them, after which the cutting

over at C C C was done, leaving a core in the centre to prop upon, which being effected, the brick arch was turned, and the centre removed. The same plan was substantially followed in other coal veins.

The North Approach was excavated through the debris, which was about the same weight as water, and as there was a considerable flow of water into the cutting, and over the top of the soft red shale, its agitation in the process of excavation converted it into quicksand, and caused some trouble in its removal (with the slide and sinks usual in such cases,) as well as in starting the tunnel. The depth of excavation at the north portal is sixty-five feet, and the lower half of the tunnel at that point is in soft red shale in place, and the upper half in the debris, with the flow of water referred to upon the top of the red shale. To those accustomed to such work, I need not relate the difficulties of the position. In order to effect an entrance there was first turned a strong façade of masonry, with an arch of fifteen feet in depth, abutting against the face of the excavation ; the heading was then started upon the top of soft red shale, thirty-two feet in width and twelve feet in height, an unusual size for a soft ground heading. The plan No. 2 will indicate the mode of propping ; plank shields were placed in the face of the heading, to prevent its running, and the frames D, E, F, with plank lagging and fore poling, were put in at distances of three to four feet from centre to centre, resting at their base, D, E, upon the more solid red shale. This operation was continued a distance of three hundred and forty feet, and until solid rock was met, with the full depth of the tunnel. The next operation was to slip the sills S, S, by a careful process, under the base of the frames, to cut away for the props, S, T, and to put in the stone abutments and brick arches, packing them carefully on the top with the rock from the tunnel excavation. When the frost was leaving the ground last spring, the superincumbent mass came down with crushing effect upon the framing, but they resisted its influence, and have since been strengthened by the arches.

## STATEMENT OF THE WORKINGS OF THE SOUTH END OF NESQUEHONING TUNNEL.

### HEADING.

| MONTH. | Feet of Holes Drilled. | Lbs. of Powder used. | Feet Progress. | Cubic Yards Progress. | Feet of Holes per Cubic Yard. | Lbs. Powder per Cubic Yard. |
|---|---|---|---|---|---|---|
| 1870. | | | | | | |
| April..... | 2740 | 1125 | 73. | 413. | 6.6 | 2.7 |
| May..... | 6698 | 2725 | 138. | 781. | 8.6 | 3.5 |
| June..... | 6779 | 4200 | 104. | 589. | 11.5 | 7.1* |
| July..... | 5862 | 4275 | 97.5 | 553.5 | 10.5 | 7.7* |
| August .... | 5179 | 2750 | 82. | 464.7 | 11.1 | 6.0 |
| September.. | 4920 | 2625 | 72.5 | 410.8 | 11.9 | 6.4 |
| October.... | 6052 | 2525 | 91. | 520. | 11.6 | 4.9 |
| November.. | 5054 | 2700 | 103.5 | 586.5 | 8.6 | 4.6 |
| December... | 4638 | 2400 | 78. | 442. | 10.5 | 5.4 |
| 1871. | | | | | | |
| January.... | 5438 | 2900 | 101. | 496. | 11.0 | 5.8 |
| February... | 6161 | 2825 | 93.5 | 520. | 11.6 | 5.3 |
| March..... | 6043 | 3400 | 104. | 589.5 | 10.2 | 5.8 |
| April..... | 6114 | 3000 | 157. | 890. | 6.8 | 3.4 |
| May..... | 5793 | 3660 | 164. | 928. | 6.3 | 3.9 |
| Total.... | 77471 | 41050 | 1459. | 8194. | 9.4 | 5.0 |

* Bad Powder. *Average, 104.*

### ENLARGEMENT.

| MONTH. | Feet of Holes Drilled. | Lbs. Powder used. | Feet Progress. | Cubic Yards Progress. | Feet of Holes per Cubic Yard. | Lbs. Powder per Cubic Yard. |
|---|---|---|---|---|---|---|
| 1870. | | | | | | |
| August..... | 2223 | 1450 | 125. | 1000.9 | 2.2 | 1.4 |
| September.. | 2584 | 2125 | 123.5 | 905.7 | 2.9 | 2.3 |
| October.... | 3491 | 2650 | 153.5 | 1237. | 2.8 | 2.1 |
| November.. | 4408 | 2700 | 120. | 1276.5 | 3.4 | 2.1 |
| December.. | 4410 | 5775 | 156. | 1002. | 4.4 | 5.7* |
| 1871. | | | | | | |
| January.... | 3667 | 3075 | 164.5 | 1158. | 3.2 | 2.7 |
| February... | 3432 | 3900 | 265. | 1701. | 2.0 | 2.3 |
| March..... | 5316 | 3900 | 215.5 | 1359.5 | 3.9 | 2.9 |
| April..... | 2653 | 1900 | 195.5 | 666. | 4.0 | 2.9 |
| May..... | 4438 | 2600 | 145.5 | 873. | 5.0 | 2.9 |
| Total.... | 36602 | 30075 | 1664. | 11179.6 | 3.3 | 2.7 |

* Partly Hand Drilling. *Average, 166.*

Mr. F. C. Collingwood succeeded Mr. Steele, with some observations on the East River Bridge foundation.

XXX.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

AT THE THIRD ANNUAL CONVENTION OF THE SOCIETY, JUNE 21ST, 1871.

## A FEW FACTS ABOUT THE CAISSONS OF THE EAST RIVER BRIDGE.

A paper read by F. COLLINGWOOD, C. E. Member of the Society.

This title has been chosen, for the reason that it is not intended to enter into a complete description of the work of building or sinking these structures, but to give only such facts as have not been already published, and which may be of interest to the profession. The first subject I wish to touch upon is that of

### INTERFERENCE OF BOLTS.

In some of the roof courses of these caissons, the number of bolts started in the course and passing through, one or more courses below, was about 5,000. Aside from this, there were other bolts coming *into* the course from the courses above, to the number of fully 10,000. It will be seen, therefore, that great care had to be taken in arranging them to prevent interferences, and the endless trouble that would thus be caused.

The timbers of the caissons, it will be remembered, were laid in courses alternately crosswise and lengthwise, and the most natural arrangement of the bolts was to place them in lines at right angles to the "streaks" of timber. This was the arrangement first adopted, but in laying out the work, the timber was found to vary so much in width, that if the bolts were placed anywhere near the centres of the streaks, it was impossible to preserve the lines in either direction, and interferences must ensue. After much study, it was discovered that by driving the bolts in diagonal lines no such difficulty was encountered.

Such lines cross *all* the timbers, whether longitudinal or transverse, and there is no necessity for the lines in *one* course crossing those in any other. If, therefore, the *lines* be placed so as not to interfere, the *bolts* in those lines can be moved forward or back, so as always to strike the centre of a stick. The

FREQUENCY OF THE BOLTS, ETC.,

was determined quite as much on practical as on theoretical grounds; it being found that to keep the timbers in place after dogging, wedging, &c., it was necessary that every stick should have at least one drift bolt every four feet.

The drift bolts were simple bars of iron, about 31 inches long, $\frac{7}{8}$ inch diameter, and slightly rounded at the lower end by hammering cold. This rounding may seem a small matter, but the holding power of the bolt depends very largely upon it. It is, furthermore, a point in which the men doing the work will bear watching, as a bolt with sharp edges drives much easier than one with a rounded point.

The holes were bored $\frac{1}{16}$ inch small for the first half, and $\frac{1}{8}$ inch small for the lower half, and it was found that a bolt driven in this manner, will hold almost to the point of rupture, before it can be drawn. This method had the advantage also of leaving the wood around the bolts solid and impervious to air, whereas "rag-bolts" would have torn the wood and increased the leakage.

The final arrangement was such, that when all were in place and the caisson complete, there was at least one bolt through every intersection of timbers. To insure the tightness of the screw-bolts, rubber washers, with slightly cupped iron washers to hold them in their places, were used under the heads and nuts. Our experience has demonstrated, however, that a

more reliable joint can be obtained by using hemp grummets and red and white lead, in place of rubber. In the New York caisson, which was lined with iron, the holes were slightly countersunk, after the iron was in place; this, with the cupped washers and grummets, insured tight work wherever any care was taken by the workmen. The rubber washers were oftentimes torn by the screw threads, and were not so reliable.

### LAUNCHING.

After settling the system of bolting, much anxious thought was given to the best means of securing a safe launch. The weight was too great to place upon two ways only, and yet this was all that could be used, without the introduction of strong supports or "launching frames" in the air-chamber. As these, for the work in sinking, were most conveniently arranged across the caisson, this at once settled the matter, as to whether the launch should be with the side or end to the water. Five such frames were put in, and the peculiar arrangement of bracing (which many noticed at the time), was especially designed to take the alternate strains of compression and extension, to which they would be subjected as the caisson slid from the ways. By means of the five frames and two end edges, seven ways were supported under each caisson, and the average pressure per square foot of surface on the sliding ways was reduced to $2\frac{1}{4}$ tons.

The ground ways were made of two 11 inch timbers, with the upper face of each chamfered, so that when bolted together, they formed an obtuse angle at the centre, with the apex one inch *lower* than the outer edges. The sliding ways were made, of course, to fit. Through the upper ends of the ground ways were passed heavy iron arbors with squared ends, and a central cam. A long lever with a squared socket was so placed upon each of these squares, as when tied down to cause the cams to project above the surface of the way. In the under side of the sliding way, pieces of iron were set, with recesses left in front, into which the cams projected. At the time of launching these cams held the caisson until the blocks were all removed, then at a given signal the ropes holding them were cut, and an absolutely uniform start assured.

Strong struts were placed upon the sliding ways at their upper end, butting under timbers left projecting from the course next the top of the caisson. These served to give the caisson a cant forward, as it arrived at the end of the ground ways, and insured its leaving them. The inclina-

tion of the ways *averaged* about $\frac{7}{8}$ inch per foot, increasing at the outer end in such a way as to give a curve with radius of about 8,000 ft. I come next to

EXPERIENCES DURING THE SINKING OF THE BROOKLYN CAISSON.

The day on which the caisson was first entered was very warm. As the doors of the air-locks all opened downward, no special difficulty was experienced on entering. On *returning*, however, the united strength of the party was barely sufficient to pull up the lower door tight enough to compress the rubber, and prevent the air escaping; and they had the pleasure of working at it some time, in a temperature of over 100 degrees, before they could close it, and open the upper door. After this experience, a small windlass and rope were arranged, so that one man could manage either door. This was nothing more than a $1\frac{1}{4}$ inch iron rod, squared for a crank at one end, and revolving in lugs fastened to the iron ladder.

Before the caisson was firmly grounded, it became necessary to remove a large boulder, which laid outside the caisson. After failing by other methods, bags of earth were thrown down outside, until the stone was completely covered, and on these loose earth was thrown. A dam of earth was next cast up inside, the water kept down by bailing, and the stone removed by undermining and tumbling it into the air-chamber. In this and many other similar cases, the air pressure kept back the water, so that it was readily controlled by bailing. The material we were excavating was almost impervious to water, and when about 10 feet below the bottom, it came in so slowly, that water pipes had to be introduced to supply the water shafts. It was not an uncommon occurrence in removing a large boulder, that an opening would be made entirely outside the caisson, for three or four feet. The only difficulty in such cases was the rapid escape of air, and increased cost of air supply.

As soon as the caisson was fairly grounded, and the regular work of excavating began, the best method of lowering became the important question. Levels were taken every morning on the masonry above, and a copy furnished the general foreman. It was made a rule that the general foreman as also the foremen of each chamber, should report to the ones that followed them, the condition of the work in their charge, the position of all boulders discovered, &c. If the caisson were level, the usual method followed in lowering was, to begin at the central frame, and loosen the

wedges regularly from the centre towards the ends. The two frames next to these were then treated in like manner, and finally the outer two. When no obstructions occurred, the blocks would all be gone over several times in the course of a day, and the caisson would settle easily, at the rate of three or four inches in twenty-four hours.

No blocking or trenches were allowed under the shoe, as the loss of air would have been too great in consequence. Two of the best men in each chamber were, however, detailed to examine under it whenever required, by removing a few inches of earth, and throwing it loosely back. It was found necessary to insist upon this being done at least once a day, and our trouble was to get even picked men to dig far enough out. The result was that frequently a boulder would be caught just against the outside of the shoe, or a bolt head, and would crush in timber and iron as the caisson descended.

In addition to these examinations, very careful ones were made every day by the engineer in charge, with a sounding rod, and the position of all boulders noted. When a boulder was found under the shoe, it was at once uncovered, and the drillers set at work. The holes drilled were 1 to 1½ inch in diameter, and the charges of powder, 1 to 4 ounces ; the latter was but rarely used. Contrary to our expectation, the effect upon the ears was not at all troublesome. This is, no doubt, due to the fact that the volumes of the gases set free by explosion, were in the inverse ratio of the pressures, and the disturbance of the air was not so great as it would have been in the atmosphere outside. It not unfrequently happened that five or six boulders would be found under the shoe at once. In such cases all lowering would be stopped, and the men put at work clearing out the centres of the chambers, deepening the trenches, &c. Although there was no trench *under* the shoe it was found to facilitate the work to trench moderately a foot or two inside.

There was no difficulty in keeping the caisson under control, so long as the work went on with uniformity, but it was always noticed, that when from any cause the lowering was discontinued for a day or two, there was a liability to sudden, and to a certain extent, uncontrollable movements. This was probably due to the compacting of the earth around the caisson, precisely as it does around a pile when driven slowly. At such times it would seem impossible to get it started, and when once movement began,

it was almost sure to split a set of blocks before it was arrested. One reason for this was, that at such times it was difficult to keep the men busy, and the trenches inside the shoe and under the frames, were sure to be dug too deep ; this in turn softened the clay, and lessened the firmness of the bearing surfaces.

When desirous of taking advantage of the weight of the caisson in lowering, the engineer at the air-compressors would be directed to lower the pressure, as each pound was equivalent to an additional weight of 1200 tons ; this was a ready and simple means of adjustment.

The greatest variation in levels on the four corners at any one time was one foot, which is a small amount when the size of the caisson and its entire freedom of movement is considered. The change in position, *from* the central line in the whole descent, was 4½ inches, and in the *direction* of the centre line (the narrow way of the caisson), 23½ inches.

### BLOCKING.

Simple as it may appear, the method of blocking finally adopted, was one out of *many* that were tried. Under every post in frames there was placed crosswise on the ground, a 12 inch square timber, 2 feet long. Across this, and lengthwise of the frame, a 4x12 in. spruce plank, 3 ft. long. Between these were placed (not driven) four oak wedges 4 inches square at the butt. The settling was first shown by the wedges being forced into the spruce planks, until they were completely buried. If not relieved, the large blocks then began to split, separating usually into two parts, and finally burying themselves in the earth.

### MATERIAL EXCAVATED.

This seemed to be a natural concrete, filled in with boulders of enormous size, one which was blasted to pieces containing probably 250 feet. Unfortunately it was not uniform in character, being at some parts very much softer than at others. Notwithstanding its general extreme hardness, when churned up as it was in the water shafts, there seemed to be washed out from it particles of extreme fineness, which were held in *suspension*, if not partially in solution, and the effect was to largely increase the specific gravity of the water. At one time, one of the shafts was idle for several days (and the water had nearly cleared itself), while the other was in active use ; and the difference in level in the water columns upheld in the two

shafts by the same air pressure, was about 9 ft. The weight of the heavier column was about 85 pounds per cubic foot.

### SIDE FRICTION.

There was but one time during the whole descent, that we had any opportunity to judge even approximately, how much this might be. At this time the caisson had been at rest for several days, on account of repairs to cars and machinery. Every effort had been made to start it down ; the blocking eased so as to have but slight pressure upon it, the shoe carefully examined, &c., and yet no movement took place, until the fall of the tide, or a slight variation in air pressure started it. The average pressure for the day was 17 pounds per square inch, giving a lifting force of 20,400 tons. The bearing surface (posts and frames,) was about 125 square feet, which at 5 tons per foot, gives 625 tons. If to this be added as much more for the pressure on the edge of the caisson, the total *upholding* force was 21,650 tons. The *weight* at the time was estimated at 27,500 tons. If these figures are correct, the weight upheld by friction was 5,850 tons. The exterior surface of the caisson contained about 13,000 square feet. Hence the friction per square foot was 900 pounds. It is necessary to state, however, that these figures are quite problematical, as there may have been, at points unnoticed, more pressure on the shoe or block, than has been allowed for. Even if these figures are correct, it would never be safe to rely upon the side friction as a means of support, except in homogenous material, on account of its great irregularity.

### WATER-CLOSET.

One of the improvements we were compelled to invent was a pneumatic water-closet. A water-tight cubical box was made with sides about 15 in., provided with seat, &c. Into the bottom of this was introduced a large iron pipe, connected by suitable bends with one of the pipes passing out through the roof, and in this was an air-tight valve. The box was kept about half full of water, and whenever the contents were to be discharged, the simple opening of the valve was entirely sufficient, the air pressure dissipating them above in a fine mist. The relief from the effluvia previously existing in the caisson, was complete.

### PHYSIOLOGICAL EFFECTS OF COMPRESSED AIR.

While the pressure ranged from 15 to 17 pounds, some experiments upon

the pulse were made by Dr. A. H. Smith, of New York, by the use of the sphygmograph. They were interesting, as at once indicating some of the effects of compressed air upon the system. The specimens I now exhibit show the pulse of the individual to have been 82 beats per minute before entering the caisson, and an hour-and-a-half afterwards, to have been 126. At another time, 84 beats, and in one hour after entering, 114 beats (and also to have been very feeble).

The first two are the most characteristic. They show a remarkable increase in rapidity of circulation while in the compressed air, and a decided change in the character of the impulses given by the heart, showing a sharp, quick beat. This sharpness of beat is much increased by exercise. The *volume* of the pulse is, however, diminished, thus indicating what was previously known by physicists, that the blood can absorb no more than a fixed amount of oxygen, and that nature regulates the amount by lessening the volume of blood sent to the lungs.

The air from the compressors passes through a spray of water to cool it, and for this reason it is always loaded with moisture. This, together with the accelerated action of the system, produces a profuse perspiration, even in the case of visitors, or those who are taking no violent exercise; and necessitates great care in leaving the caisson, to avoid chills and exposure, especially in the air-lock. It is hoped that the steam coils provided in the locks of the New York caisson may obviate this difficulty to a large extent.

### CANDLE SMOKE.

One of the things yet to be invented, is a candle that will not smoke in compressed air. Whoever *does* this, will be a public benefactor, for the smoke is an unmitigated nuisance. This is due, no doubt, to two causes. The gases liberated by the heat, are under the abnormal pressure, and therefore, reduced in volume; hence there is a smaller flame, and less surface exposed to the oxygen of the air.

Again, the heat due to the combustion of a fixed quantity of gas, is itself an unchangeable quantity. In the normal atmosphere, this is sufficient to create a circulation of air about the flame, by heating and rarefying the particles that come in contact with it. Of course when the density of the air is doubled, twice as many particles as before have to be heated, to create the same circulation, and the result is that much of the time a large part of the carbon passes off unconsumed, for the lack of a proper supply

of oxygen. Whether it is a fact that the increase of pressure requires an increase of temperature, for the proper chemical changes to take place, I cannot say.

CONCRETE.

The filling in of the chambers, after the sinking was complete, was a very simple matter. Bulkheads of boards, about 3½ feet wide, were built across the chambers, and the concrete filled in these in layers of from six to twelve inches, and each allowed to set before the next was put on. The layer next the roof layer was left sloping about six inches from rear to front and after setting, a finishing layer was rammed in between it and the roof with iron rammers. No difficulty was ever experienced as to the concrete setting; and on one occasion, having to remove a portion, we found it had already acquired a considerable degree of hardness.

I have thus touched lightly upon some of the most prominent features of the work. It has been so fully described in reports, &c., however, that I have thought best to omit many things that would otherwise be of great interest.

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After reading the paper, Mr. COLLINGWOOD, by request, continued his remarks, as follows:

In reference to the great difference in level of the two columns in the water shafts, at one time observed, one of the shafts had not been in use for several days, and the water had become almost clear, while the other had been in constant use up to the time of the occurrence. The difference in level was so great, that a stream of water had been turned into the heavier column by those in charge outside, for fear of some accident. I was inside at the time, not knowing that this had been done, and was surprised to find the water in the pool underneath the shaft overflowing, and filling the trenches.

As the columns in the shafts were entirely supported by the air pressure inside the caisson, and were a direct measure of the same, my first impression was that some accident had befallen the compressors, and that the air pressure was running down in consequence. I, therefore, went above, to discover the cause, and found the condition of affairs as follows:

The water in one shaft, about 12 feet from the top ; that in the other, about 21 feet from the top, and remaining stationary, or nearly so, notwithstanding a heavy stream of water pouring into it. The water was at once shut off, and on weighing a sample taken from the shaft, it was found to weigh about 85 pounds to the cubic foot, being fully 21 pounds in excess of the weight of that in the other shaft.

The water-shafts were large tubes, 7 feet square, reaching from the air above, down through the masonry and the roof of the caisson; and extending 20 inches below the edge of the caisson. They, therefore, were lower than any other part, and required especial care and watchfulness to prevent injury from boulders or hard earth under the edge. The height of the water in them was (as I have said) regulated by the air pressure in the chamber, and, as a safeguard against accident, we never allowed the water in the pool at the bottom to get down nearer than six inches to the bottom of the shaft. Whenever a shaft was not in use, it was necessary to work occasionally with poles underneath the edge, so as to be sure that there was a free communication between the column and the pool. If this were *not* done, the material in suspension in the water would settle down, seal the edge, and be liable to cause a dangerous excess of pressure on the pool. If this became great enough, the water would find some small opening eventually, and run down rapidly in the pool, until the edge was exposed ; then the air would find vent, and cause an instantaneous rush of all the excess of air in the chamber, out from the shaft ; carrying with it water, mud, and rocks to a great height. This only occurred once during the progress of the work, at a time when all the workmen were absent. The precaution was usually taken of leaving a small stream of water playing into the shafts, but in this case it had not been done, and on Sunday morning the "blow-out" took place. It was described by those who saw it as presenting much the appearance of a miniature volcano.

In the course of the work it became necessary to blast rocks from underneath the edge of the water-shafts. It had been hoped that the dredges would work their way downward in the original bottom, and that the blasting might be dispensed with. The boulders proved to be so large and numerous that this was impossible. To remove the water from the shafts, the expedient was adopted of bolting on the top a strong air-tight cover. By means of pipes connected with the interior of the caisson, compressed

air was gradually admitted above the water column, and the water slowly settled, and overflowed into the trenches, from whence it was syphoned out. The hole was then bailed dry, the boulders blasted, and the excavation made complete to a depth of about 5 feet below the shaft. The process of refilling was the most dangerous, great care being necessary that the air pressure above was not let off faster than the water was supplied in the pool.

Mr. McDonald asked whether he understood that the water in the shafts had been weighed at the time of the great difference in level ?

Mr. Collingwood : I *did* weigh it, and found the water in one about one-third heavier than that in the other.

Mr. Arthur : Did you attribute it to heavy material in suspension ?

Mr. Collingwood : It could have been nothing else than heavy material either suspended or in solution. Very muddy water would weigh more, of course.

In reply to other questions, as to the effect of compressed air upon the system, Mr. Collingwood said : I frequently found that my pulse was so feeble that I could hardly count it. Inhaling the carbon given off by the candle, made many of the men cough more or less for a month after the work inside the caisson was finished. This was true in my own case, and, even now, I occasionally expectorate small quantities of it, after a lapse of four months. The usual time spent inside, continuously, was four hours. On two occasions I remained from six to seven hours, and in each case felt exhausted afterward, and my system was somewhat deranged for a day or two. This was with a pressure of about 15 pounds above the atmosphere. With a higher pressure it would have been dangerous to remain so long.

In reference to the light, we had complete arrangements for the use of calcium lights, but the supply of oxygen was extremely uncertain. These were a great relief when we had them, as we were then obliged to use candles at points under the shoe only. We used the street gas constantly for fixed lights, but the freezing of pipes and other contingencies, rendered *these* also at times uncertain.

Col. Adams asked : What is the general state of the atmosphere in regard to moisture ?

Mr. Collingwood : It is always at the point of saturation, or nearly so. The escape of a small quantity of air, therefore, produces a dense fog.

Col. Adams : Could you not use reflectors ?

Mr. Collingwood : They were not tried thoroughly, but an experiment made with them was not satisfactory, on account of the constant condensation upon them, together with the deposit of lamp-black, &c., induced.

Mr. Arthur asked the nature of the instrument by which the pulse tracings were made.

Mr. Collingwood described it as a delicate lever pivoted at one end, and carrying at the other a point supplied with ink. This point pressed lightly against a strip of paper, which was carried along by clock-work, so timed, as to run its course in ten seconds. Pressing against the lever near the pivots, was a point connected to a spatula-shaped piece, resting upon the pulse of the wrist. The lever was thus thrown up by each beat of the pulse, and produced the wavy lines shown in the tracings.

Mr. McDonald said : You speak of the downward pressure having the effect of crushing the intermediate supports you made use of in the Brooklyn caisson. Do you not expect a greater pressure in the New York caisson on account of the increased depth ?

Mr. Collingwood : The *total* pressure will of course be greater, but the bearing surface of the frames has been so much increased, that we anticipate no difficulty.

Mr. McDonald : Was the cutting edge made use of in the Brooklyn caisson ?

Mr. Collingwood : It was of no avail, on account of the extreme hardness of the material.

Mr. McDonald wished to know whether the shape of the edge had been changed, and what it was ?

Mr. Collingwood : The section of the edge showed a quadrant of 2½ inches radius, joining the outside vertical line and the inner curve; which latter had a radius of about 11 inches, and was tangent to the inside of the caisson—the inside making an angle of about 40 degrees with the vertical. This made the horizontal distance between the two tangents, at their lower ends, 8 inches.

Mr. Arthur asked how the water was removed from the caisson, after flooding it, at the time of the fire.

Mr. Collingwood : At this time the edge was so far below the bottom, that the water could not go out under the edge. We had, therefore, to

force in air, at sufficient pressure, to cause the water to overflow the water-shafts. The pressure was increased until, at the close, when all was out that could be safely removed, it was 21¼ pounds, in addition to the atmosphere.

Mr. McDonald asked whether the batter of 1½ inch to the foot, given the outside of the caisson, was considered advantageous, and what was its object?

Mr. Collingwood: The *original* intention of this was to prevent the caisson from rising and falling with the tide, when the excavation had as yet but little depth. This was finally accomplished, by allowing sufficient overweight to overcome the buoyancy at high tide. The reduction of side friction was also an object, and for this it was of much use.

Mr. McDonald asked if it were not desirable to have the side friction as great as possible, to relieve the strain on the interior supports?

Mr. Collingwood: In our experience, it is not, because of its great irregularity. At one time the friction would be so great that we could scarcely get the caisson to settle at all, and at another the motion was too rapid. We hope it will be more uniform on the New York side, on account of the absence of boulders. The excavation will there be mostly sand. To a moderate degree the downward pressure can be governed by the air pressure, as the latter is a lifting force.

Col. Adams wished to know if we had not quicksand to pass through in New York?

Mr. Collingwood: There is a considerable body of it, but we do not anticipate trouble in working it, as the air pressure will keep it back.

Mr. McDonald argued that the form adopted was not so favorable for strength as one with vertical sides, and that the friction after all is only relieved for a few feet from the cutting edge by reason of the slope. On the New York side there would undoubtedly be friction from the very point of the cutting edge upward, and it does not look as if the cutting edge, which projected outside of the line of strain, would be so likely to keep its form as one that was vertical. The Brooklyn one had been somewhat distorted in sinking, and it seemed to him that vertical sides would have been preferable.

Mr. Collingwood answered at length, as follows: This whole matter was thoroughly investigated, and the conclusions reached seem to have

been justified by experience. It must be borne in mind that the outside was vertical for about 2½ feet. The idea from the start was, that there should at *no* time be more than a certain weight, say 7,000 tons, resting upon the edge and other supports. These computations were made on the supposition that the air pressure was kept up to an amount, equal to the pressure due to the head of water outside, above the cutting edge. The state of the tide had always to be considered, since this made a variation in external pressure of 2½ pounds per square inch.

Until the edge was sunk some distance in the earth, this had to be governed by the compressors. As the tide was rising they were run rapidly, and when falling, they were almost stopped. The variation in internal pressure, caused thus a change in the buoyancy of the caisson (which was opposed of course to its weight) of about 3,000 tons. In other words, the pressure on the supports was 3,000 tons more at low than at high tide.

The computation then was this : given a certain bulk of timber, stone, &c., its weight was the total pressure *downward*, disregarding side friction. Given also a total depth below high or low water, there was so much water displaced, the weight of which was the total *lifting* force. The difference *between* these was the pressure on the supports, disregarding friction. It was calculated that if the whole weight of the caisson came upon the supports, even with no air pressure, their bearing power was sufficient.

In the Brooklyn caisson, our experience was, rather a danger from forcing inward, than from spreading of the sides. In every case we found the timbers to have slipped inward, if at all (in one place several inches,) owing no doubt to the hardness of the material passed through.

Mr. Steele. remarked that this subject was under discussion at one time, and the impression of Mr. John A. Roebling was, that there would be *no* pressure on the cutting edge at all, that the forces below would flood the whole thing. The experience with the Brooklyn caisson had been somewhat different. His fear was that there might be trouble from a *lack* of weight. When you drive a pile, the sand closes around it, and, if left standing, it is difficult to start it again. The fear was that a similar thing would happen with the caisson, and to some extent this has proved true.

XXXI.

# AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

AT THE THIRD ANNUAL CONVENTION OF THE SOCIETY, JUNE 21ST, 1871.

## THE ANTHRACITE COAL TRADE AND LABOR QUESTION, AS CONNECTED.

A paper read by MARTIN CORYELL, C. E., Member of the Society.

For the year 1820, the Lehigh Coal and Navigation Company reported 365 tons of anthracite coal sent to market.

In 1822, the same company reported 2,240 tons carried on their canal, and the Schuylkill Canal Company reported 1840 tons; total, 3,720 tons, for the year 1822—equal to one day's production of seven good collieries, and seven ordinary railway coal trains.

The annual production of anthracite coal for the year 1870, is given at 15,849,899 tons.

These facts clearly demonstrate that anthracite coal is a staple article in the necessities and requirements of the people, and is so much more effective, labor-saving, and cleanly, than any other fuel; and while its selling price is kept within reasonable bounds, it cannot be superseded; and as population and manufactures increase, so will the consumption of this coal, if capital, engineering skill, and labor are left untrammeled.

The older members of the profession know the difficulties under which

*outlets* for coal were made, and how wearying it was to induce capital into the enterprise, and how pecuniarily worthless coal and coal lands were in the rock-ribbed mountains, and the wilderness, without the means of reaching the populous portions of our country, where it could be consumed to advantage and profit.

To promote and encourage the building of these *outlets*, liberal grants and privileges were given by the State Legislature, and some States in their sovereign capacity, assisted in constructing and extending these *outlets*.

The State of Pennsylvania contains within her bounds all of the available anthracite coal worth naming in the United States.

But the large majority of the capital invested in the *outlets*, in the ownership of coal and coal lands, in the collieries and transportation facilities, is furnished from without her borders.

There are three distinct coal-fields, known generally as the Southern, Middle and Northern coal-fields, and there are four grand *outlets* to reach the New York or Eastern market.

The coal from the different coal-fields differs in quality and cost of mining, also in the cost of transportation to the common market at New York; and without intending to be invidious, or to provoke discussion, I would state generally that the Middle coal-field ranks first in advantages, the Southern next, and the Northern last.

Here arises the difficulty of fixing a uniform rate for mining coal by the car or ton, and a uniform price per ton, at a common market.

It is very generally conceded that the average wholesale price of coal per gross ton, at the ports or landing near New York City, such as Weehawken, Hoboken, Port Johnston, or Elizabethport, should be five dollars, so as to fairly remunerate all the interests connected.

These are the details from an ordinary colliery, based upon the price of five dollars per ton.

| | | |
|---|---|---|
| *Outlet*, Rail and Canal.. .....30 | per cent., | or $1.50 per ton. |
| Owners of coal land and works, 10 | " " | 50 " " |
| Colliery and Stock.....10 | " " | 50 " " |
| Outside labor & superintendence 10 | " " | 50 " " |
| Miners' and mine labor.....20 | " " | 1.00 " " |
| Transportation.... .....10 | " " | 50 " " |
| ommission..... 5 | " " | 25 " " |
| fit.... ..... 5 | " " | 25 " " |
| Total.... .....$100 | per cent. | $5.00 per ton. |

Of these outlays the first four items, amounting to 60 per cent. or $3 per ton of coal, is a permanent outlay, and must first be provided for before the mining can commence, which is 20 per cent. or $1.00 per ton of coal on the price of $5.00. And this is not permanent, or paid in money, but is contributed by labor, and is taken out again in money, at the monthly pay day; and since the Laws of the Commonwealth ensure this portion of the investment against all risk or loss, to the amount and value of the colliery and stock, at least 40 per cent. of the investment is made to insure 20 per cent. every thirty days to the miner and laborer.

Under these circumstances and some others, the miner and laborer find sufficient inducements to invest their labor at a colliery.

Such a moiety of capital as 20 per cent. and that fully insured, and under his control every month, should not give either miner or laborer the right to dictate how work should be done, at what prices coal from each colliery should be sold, and in what quantities.

As a general rule the first three divisions, amounting to 50 per cent. or $2.50 per ton, have a uniform price, running by the year or for many years; consequently if a rise in the price of coal is brought about, it does not enure to the benefit of the three first divisions, or to the two last divisions; so that if a rise of two dollars per ton can be effected on the annual product of 15,750,000 tons, it would take from the consumers $31,500,000, to be distributed among 30,000 miners and laborers, and say 10,000 speculators and middle men.

A regular supply and a uniformity of price, and that as low as practicable, is the true method by which the annual increase of anthracite coal can be kept up, and by moving large quantities regularly and not spasmodically, the transportation can be greatly cheapened to the consumer.

Public attention is being directed to the danger and difficulties of mining, and to the fact that mine labor has not received the reward it deserves.

In all branches of labor, mechanical and engineering work, a portion has to be accomplished under difficulties, and at great risk of life, limb and health; and such labor should, and does command a corresponding price.

The miner's occupation is no worse than many other trades in all these respects, and none are better rewarded than the miners as a class; and very many accidents and afflictions are brought upon themselves by their

ignorance of the work they undertake, their perverseness, and a determination to risk their lives rather than to be at the expense and trouble of securing themselves from danger.

The system of mining now followed in the anthracite regions is extremely wasteful, and most unsatisfactory.

One half of the coal in a seam is wasted ; much money is uselessly expended in the getting and preparing.

The term "skillful miner," should be applied to such men as can and do get all of the coal out of the mine, and leave all of the slate and dirt if at all practicable, within the mine. "Skillful," should not apply to those who get the most coal out at the least expense to themselves, and leave behind as much as they take out, because it requires extra care, cost and exertion to secure it.

This practice comes from the baneful effects of contract work,—of cutting coal by the ton or car,—and has demoralized the entire mining community.

The miners, by combination and collusion with the "boss," establish the price per ton or car, for the working of breasts or gangways that are attended by some extraordinary difficulties, and then, under the rules of their associations, all members must have the same price, or all must stop work.

Those who were fortunate in having secured a good breast, can in three or four hours earn or accomplish their day's work and leave the mine, whilst their laborer must remain in the gas and powder smoke, and be exposed to all the dangers of falling coal and rock, and load into cars the coal the miners have cut, and his wages are but little above ordinary labor.

When a breast or seam of coal proves difficult to work, the miner abandons it, gives it a bad name, and it is virtually lost to the owner.

If men are employed by day's work, and paid regular wages, they invariably idle their time, and make the cost so excessive, that contracts are almost essential to accomplish the needed work. Should the mine boss or manager interfere, or discharge men for such conduct, the association is notified, and from them issues a mandate for a "suspension," until the boss is discharged, and the men reinstated.

There exists no friendly feeling between the employer and those employed. The former feels that he was imposed upon and the latter is

assured that he will not get another good chance, and so soon as business relations are finished they willingly separate, and as neither party made any efforts to make the house and home of the miner's family agreeable and cheerful, there are no ties or associations to induce a further stay.

My conclusions are, that cheap coal can only be furnished and maintained by the employment of competent civil and mining engineers, mechanical engineers and mechanics, in connection with skilled miners and extraordinary labor.

Close and specific accounts should be kept at all collieries, and strict accountability be maintained.

Work generally should be done by the day, and at wages in proportion to the risk encountered, and all coal in the seams should be made available, and the good coal and that easily mined should be made to pay for the poor coal, and that more difficult to mine and prepare.

It should be the duty of the mining engineer, mine boss, and their assistants, to make every portion of the mine as safe and secure as an ordinary quarry, or other engineering enterprise, and with as healthful and pure an atmosphere for the majority of the workmen; and when extra hazardous work is required, let the necessary cautions be taken.

More attention should be given to provide home comforts for the miner and laborer, and their families, also a hospital, and to establish at each colliery police regulations similar to those in village charters, and for the same purpose, and these provisions should be considered as a part of the annual compensation to each person, in proportion to his annual earnings.

And further, each colliery should be credited in the annual averages of wages, for the benefits of all improvements of whatever kind are provided for their men, either in safety in and about the mine, or labor-saving appliances in getting from or to their work, and in the convenient and abundant supply of good and wholesome water.

By so doing, our mining region would not present the desolation that many portions do, by dilapidated and abandoned dwelling houses and breakers, and the sad reflection that millions of tons of good coal have been, in an engineering sense, disreputably wasted from the owners and future consumers, and *capital* expended without having accomplished its useful effect upon its possessor, and the great interests of the country.

Mr. STEELE made the following observations on the subject of Mr. CORYELL'S paper :

Our able brother has touched on subjects which are of vast importance. This question of labor, is worth while to be discussed here. It is a mighty question ; one which involves, at this time, very great interest.

This organization in the coal region which he speaks of had its origin undoubtedly in an amount of oppression to paid labor, which has never had its equal in the civilized world. We must not look, therefore, at these great strikes as mere emanations from a bad spirit. They originated from a necessity, which was improperly transplanted into this country, where perhaps they will not have a very vigorous growth.

It is a great question, however. We have seen 40,000 men arrayed in our coal regions against capital. The organization was so perfect that capital could make no impression upon it. It was such an organization as I really believe no capital is capable of effectually opposing. You cannot get any amount of capital so effectual, so perfect in all its parts, as this organization of labor ; hence its success. Yet measures are taken to secure greater safety in the mines, to secure arbitration, and various things of that kind, and I have no doubt that in time they will yield to the effort which has been made, and the circumstances which have been brought to bear upon them.

This is a political subject, involving statesmanship as well as civil engineering.

He has referred to another subject, that is, to the waste of coal, in the present system of mining. I have in my mind one of the most valuable portions of the coal region, in which 10,000,000 tons of coal are taken out and 10,000,000 tons are left there. There are some of the dirt heaps, out of which the extraordinary amount of seventy per cent. of marketable coal is extracted. I would like to hear from Mr. Rockwell upon this subject, which he understands so well.

Mr. ROCKWELL : I don't know that I can state much more than has been stated by Mr. Steele. My estimates brought the waste to sixty per cent. of the whole amount of coal that was worked there. The company had actually sold one-third of the coal that they had worked, and had wasted two-thirds of it. So it is throughout the whole of the anthracite

region, one-half fully is waste. More than one-third of the coal is left in the mines, and the mountains of coal dirt, as we call it, show how much is wasted on the outside. The uninitiated think more of that than they do of what we waste inside. They do not see that we actually leave more than one-third in pillars. It is a question not very creditable to the mining engineering part of our profession; but the fact is so nevertheless.

In other quarters where they have veins as large and as difficult to work, they have long since got beyond that stage of work where they waste one-half of the coal. They have now got where they have reduced the waste to one-eighth and one-tenth, and in some places they take it all out. It may be that it would cost a little more per ton to mine the coal in that way, but when you consider that you get all the coal, the landlord would be better off by getting a smaller amount per ton, on the condition that it were all worked out, than he would by getting a present royalty on one-half of his coal.

The question has assumed such a great importance in the anthracite region, that it was one of the main reasons for the organization of the society, which will be announced presently from the Chair. It is an Institute of Mining Engineers, who have taken hold of the subject, and who propose to investigate the cause of the waste in mining. It is a subject, I think, which deserves the attention of engineers, and one which is of vast importance to the country. The prosperity of the country at large, and more particularly that of the State of Pennsylvania, depends so largely upon its anthracite mines, that it is a subject which takes precedence of almost all others in the State.

The Vice-President stated that Mr Rockwell had informed him of the organization of such a society, and for the purposes mentioned.

Mr. Coryell: I wish to state that mining engineering has been some what guilty in this matter; but, I assure you, a good mining engineer has never had much credit up there for attending to any of these little matters which make economy and save money, and they have been over-ridden by this system of mining coal by contract. No good engineer is allowed to direct any good mine, and it is only the engineers who permit those things to go on, who have any success.

Mr. Casimir Constable presented a paper on "Arch Beams."

XXXII.

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AT THE THIRD ANNUAL CONVENTION OF THE SOCIETY, JUNE 21ST, 1871.

## ARCHED BEAMS.

A paper presented by CASIMIR CONSTABLE, C. E., Member of the Society.

On this subject the profession in this country have a few strictly mathematical treatises too general and complicated for the practical man, while few have the time or inclination to wade through pages of long formulæ, often to find little which they can directly apply in practice.

We very much need a clear, concise statement of the main facts pointed out by theory*; simply formulæ for the maximum strains in the different cases to be met with; the points where those strains occur; and the general nature and direction of the curve which the maximum strains would describe if they should be plotted out for every point of the arch. To illustrate what is here meant: In the arch free at the ends, the maximum strain is at the haunch, about $\frac{1}{4}$ the span, and $= T$, at the centre $= T_1$ at the

* This paper was written a year before going to print, since which time several articles have appeared which throw great practical light on the subject. B. Baker on "Strength of Beams, Columns and Arches," lately published in England, treats the subject in the manner suggested.

spring $= T_2$; then the maximum intermediate strains are expressed by a parabolic curve from $T_1$ to $T_2$, with its vertex T; these three strains may be laid off to a scale, and it is not necessary to know the intermediate ones, but only to describe by eye such a curve between them; since the actual assumed strain is always in excess of these (T, $T_1$, $T_2$), the maximum.

Often the letters of formulæ expressed by the calculus are too vaguely defined to allow of their being used; this is to be much regretted in the excellent formulæ on this subject in Rankine's Civil Engineering.

Very seldom does it happen that the size and cost of an arch bridge will warrant the adoption of the long calculations, however, which are indulged in by foreign Engineers, and thus "straight truss bridges are often met with where arches might have been more economically employed, had their theoretic calculations been as simple and as familiarly understood as those of the former."

Now, the following reasons in part show that theory, after all, only approaches the real strains existing in a metallic arched beam. First, the known variable elasticity in different parts of the same piece, whether of iron or steel. To this must be added a settlement or pressing apart of the abutments or piers; this if properly constructed ought not to cause much change in the problem, but still would effect it somewhat. Again, if the feet of the arch are keyed up with wedges, it is almost impossible not to drive one tighter than another, and thus change the position of the line of pressure, as well as cause an initial strain. Then, again, there may be weak riveted joints, or in the case of butt-joints an inaccuracy in the angle of the faces, so that more strain will be borne by one side than the other. Also, though the arch be erected with an increased rise, so that under a total maximum load the deflection will make it coincide with the curve of pressure, yet under any other load, or with strain due to temperature, the line of pressure will pass nearer the outer edge, causing increased compression in that edge per square inch. Hence, so long as the nice mathematical elaborations depend upon assumptions not strictly perfect, their accuracy is illusive. While all these and other causes tend to form doubts whether theory can be closely followed, it may be said that the maximum assumed loads seldom if ever occur, and if a large factor of safety is taken, the corresponding strain per square inch, should it slightly exceed calculation from any of the above causes, would not cause injury to the structure. Also the play at the joints, which can not be calculated, in

many instances will cause the theoretical strain due to temperature to be overestimated. Besides, in practice it is more economical to retain the section constant through long distances than to continually vary it to conform to the strains at each point, and since practical reasons do not warrant a too close refinement of calculation, we may content ourselves with approximate formulæ, and for only occasional points, so long as they are based upon what is considered accurate theory.

A review of the principles which govern the strains in beams, straight or curved, may not be superfluous, for although the strains in an arched beam differ from those in a straight one under the same amount and position of load, the moments which produce those strains (called Bending Moments) are the *same* under certain conditions.

Therefore take the general case: *of a beam covered throughout by a weight* ($w$) *per running foot, as for instance its own weight, and also by a load* ($w_1$) *extending from one end* A, *a distance* ($s$), *as of a train covering that part of a bridge*, then:

1. The curve of moments will be two parabolas with their vertices over (D) where the load ($w_1$) ceases. Fig. 1.

2. The strain in chords or "members" of the beam, or arch, will be at any point: the moment at that point, divided by the vertical distance from that point to the horizontal line, passing through the points of support of the beam.

3. If ($w$) is omitted, then the loaded side is a parabola, the unloaded a straight line tangent to it at (D).

The equation of the bending moments for the loaded side is,

$$M_x = -(w \times w_1)\frac{x^2}{2} + \left[\frac{w_1}{l}(2sl - s^2) + wl\right]\frac{x}{2} \qquad [A.]$$

in which:

$M_x$ = vertical ordinate expressing moments at $x$.

$l$ = span.

$x$ is measured from A towards B.

Making $\frac{d(M_x)}{dx} = 0$ (first differential coefficient)

we shall get the value of $x$ where the moment is a maximum, namely at ($c$). That is A $c$ or

$$x = \frac{wl + \frac{w_1}{l}(2sl - s^2).}{2(w + w_1)} \qquad [B.]$$

*Discussion of the equation:*

If $w$, $w_1$ and $l$ are kept constant, while $s$ is made to vary, $x$ may have an infinite number of values between the limits

$$s = 0 \text{ and } s = \frac{l}{2}.$$

Also by substituting the different assignable values of ($s$) we may obtain any number of curves of moments, all differing, corresponding to each position of the load.

Suppose the load to occupy half the beam (which in the case of an arch produces the greatest bending moment due to the passing load), $s = \frac{l}{2}$ and the point of maximum bending strain is:

$$x = \frac{w\,l + \frac{3}{4}\,w_1\,l}{2\,(w + w_1)}$$

A parabola from A to B whose semiparameter was $\frac{1}{w}$ would express the bending moment due to $w$; and one with semiparameter $\frac{1}{w}$, from A to $x$, and a straight line from there to B, will express the bending moment due to $w$, over half the beam.

Or, 2d, making $s = \frac{l}{2}$ in equation [A.]

$$M_x = \frac{x}{2}(\tfrac{3}{4}\,w_1\,l + w\,l) - \frac{w + w_1}{2}\,x^2 \qquad [A_1.]$$

from which the curve may be calculated. If $w = w_1$— then

$$x = \frac{7}{16}.\,l$$

and the equation of moments would be

$$M_x = (\tfrac{7}{8}\,x - x^2)\,w\,l$$

from which the curve of moments can be calculated and plotted, as in Fig. 1.

N. B.—If the parabolas above are used, the sum of the ordinates of the two curves due to $w$ and $w_1$, will equal the ordinate $M_x$ calculated by the formula.

Curve of Pressure.

I.—The curve of pressure is identical with the curve whose ordinates are the moments of rupture, if these latter are laid off by such a scale that the middle ordinate coincides with neutral axis of the beam.

That is, if on A B, the span, Fig. I., the curve of moments is laid off to such a scale that C D = rise of the arch, then this curve may be taken for the line of pressure or the resultant of the forces acting on the beam.

To ascertain the chord strains due to the bending moment $M_x$, formula [A], it is only necessary to divide $M_x$ by the depth of the beam. In a "straight beam" the depth is constant, in the segmental arch it is variable, being the rise of the arch at whatever point ($x$). $M_x$ happens to belong. Thus the strains vary as a parabola in the "straight beam," and are constant in a parabolic beam, that is the arch, though the moments of the forces in each or any beam are the same. N. B. Further on it will be shown that there is in an arch, as in a pair of rafters, yet another bending moment ($M_1$).

II.—If the axis of the beam coincide with the curve of pressure, then will the arch be in equilibrium. That is, the strains at any section will all be compressive, and, acting, in the direction of the neutral axis, there will be no external bracing of spandrel or web needed to keep the arch in position.

This only occurs when the beam is arched, and herein is the main difference between an arched or curved beam and a straight one. Practically, in the arched beam this only occurs when it is loaded symmetrically with the centre, and also the rise of the arch, if circular, must not be greater than $\frac{1}{10}$ the space. For a greater rise the circle would vary too much to coincide with the parabola, which is the curve of pressure.

The curve of equilibrium or of pressure will differ from the parabola somewhat, if the weight of the arch is great compared with the horizontal distributed load. If the load is carried to the arch by radiating spandrels, then the curve approximates to a circle, and the horizontal member receives a tension due to the horizontal component of the load acting in the direction of the radial struts.*

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* Transactions Institute of Civil Engineers of England, Vol. XXXI, for 1871. Mr. Brereton gives the following as approximately true:

1st. With uniform, horizontal load, in proportion to the weight or rib or chain as 6 to 1, applied vertically, the curve of pressure would approach very near the parabola.

2d. With the same 3 to 1, curve midway between the parabola and the common catenary.

3d. With the same in proportion 1 to 1, the curve would be near the common catenary,

4th. With same applied through radiating spandrels, proportion 3 to 1, curve would be between equal catenary and the circle.

5th. With the same 6 to 1, radiating curve would approach closely to the circle.

In all these if the arch be flat the difference between each would be practically insignificant.

The introduction of these radiating spandrels would, we think, admit of better æsthetic treatment in the design than vertical ones.

The advantage of the arched beam being to reduce the strains in the web to nil, under the uniformly distributed load, a curved top chord to bridges has often been adopted; but unless the form be that of the bow-string girder, the constructive difficulties and complications generally counterbalance, in the extra expense, the amount of material saved.

III.—According to (II.) the above, it is evident that if an arched beam be subjected to a passing load (as on a bridge), in order that it may always be in equilibrium, its axis must assume a different curve for each new position of the load. But since the arch, to maintain itself, must be rigid, this continual change of form is inadmissible, and therefore it is that only under a full load is the arch in equilibrium. Since under any movement of the load (passing) the axis of the beam can no longer agree with the curve of pressure, which depends upon the varying moment, the structure will not be in equilibrium, and consequently will require the aid of bracing to resist the tendency to seek such equilibrium.*

IV.—The maximum strain in the chords of a "straight beam" is caused when a full load covers the entire beam; in the case of an "arched beam" this is not so: the new condition, that the arch shall retain its form when subjected to a passing load, necessitates that the line of pressure or thrust no longer agree with the axis of the rib, as when uniformly loaded. This causes another Bending Moment ($M_1$), namely: the product of the thrust, due to this passing load, and the vertical distance from the same to the axis of the arch round which it tends to cause rotation. A D B (Fig. 1), being the axis of the rib, and A P $P_1$ B, being the line of pressure, then the Bending Moment due to the passing load tending to cause revolution round any point ($d$) of the axis is $M_1 = P \times$ distance $p\ d$.

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* The inverted arch or suspension bridge does not require this rigidity to maintain itself, and consequently was, as first constructed, allowed to assume a curve of equilibrium, due to each position of the load. But this flexibility allowed vibrations, both from wind and the motion of the load, as the trotting of cattle or marching of men, which vibrations assumed a wave-like motion so great as to cause the destruction of many otherwise strong bridges. The introduction of stay rods from the towers to the floorway, and of an auxiliary truss, was therefore indispensable; hence one of the main points of advantage in point of cost, of the suspension over the arched bridge, was removed—that of not having to allow for the effect of the passing load.

Now, since the line of pressure (Fig. 1) passes above the axis on the loaded part, and below on the unloaded, this new bending moment will be + (or compression) in the former, and — (or tension) in the latter.

V.—This extra bending moment, and the consequent strain in the flanges of the beam, form the difference between the "arched" and the "straight" girder; therefore, before proceeding to the actual strains, I will somewhat anticipate by adding:

The point where $M_1$ is greatest is about $\frac{1}{4}$ span, exactly that amount when the bridge is half loaded. Here the line of pressure will vary most from the axis of the beam. If it approach too near the outer edge, the opposite edge will be relieved of all strain of compression, and will tend to open —; $p\ d$ must therefore have a limit, conditional with there being no tension in the opposite edge. Such values of $(p\ d)$ in terms of the depth of the rib, are derived from the moments of inertia of the cross-section of the rib, and are as follows:

$$(p\ d = q\ h).$$

For a rect. solid beam $q\ h = \frac{h}{6}$.

" solid circle or ellipse " $= \frac{h}{8}$

" hollow square " $= \frac{h_1}{6}\left(1 + \frac{{h_1}^2}{h^2}\right)$.

" hollow circle " $= \frac{h_1}{8}\left(1 + \frac{{h_1}^2}{h^2}\right)$.

Where $h$ and $h_1$ are the external and internal depths.

For a rolled beam-section of rib $A_1$ = sect. each flange $A_2$ = sect. web

$$q\ h = \frac{h}{6}\left(1 + \frac{4\ A_1}{A_2 + 2\ A_1}\right),$$

For a beam with braced web, as the Coblents, $q\ h = \frac{h}{2}$,

$h$ being distance between centres of gravity and flanges.*

VI.—*General Equation of Moments, and hence the strains, in flanges of an arched beam.*

We have now seen that while the line of pressure coincides with the neutral axis of the rib, the moments are the same as in a straight girder; but that when the load is other than symmetrical with regard to the centre, there is a

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* See Rankine, "Civil Eng.," p. 295.

$M_1 = P\ q\ h.$

second bending moment, due to what we call the passing, that is, variable load; hence $M_x$ must be modified to

$$M_x = M \pm M_1.$$

The final term (M) coinciding with $M_x$ in equation [A.]

This may further take the more definite form

$$= \frac{W\,l}{8} \pm \frac{W_1\,l_1}{8} \cdot \frac{1}{z}$$

where $W = (w + n\,w_1)\,l$

and $l_1 = n\,l = s$ in equation [A]

and $z$ is a factor.

Where $n = 1$, $M_x = \frac{W\,l}{8}$

the arch fully loaded.

VII.—*Strains due to the above moments.*

Dividing by lever arms $d_x$ = rise of arch, $h_x$ = depth; $d$ and $h$ vary at each point ($x$).

$$T_x = \frac{M}{d_x} \pm \frac{M_1}{h_x} \qquad [C.]$$

or

$$T_x = \frac{W\,l}{8\,d_x} \pm \frac{W_1\,l_1}{8\,h_x} \cdot \frac{1}{z} \qquad [C_1.]$$

Two cases will be particularly treated of in what follows—the *independent arched beam* and the *continuous arched beam;* the former allowed to move by means of pivots or circular sockets at the abutments, and hence similar to the straight girder free at the ends; the latter bolted fast at the ends (encastrée), and similar to the continuous straight girder.

VIII.—The positions of the passing load on an arch which produces the maximum thrust are two, namely, the span half covered, and $\frac{5}{8}$ covered.

1. Half covered produces maximum strain in upper flange of loaded half. For the continuous arch, there is a point of contrary flexure about $\frac{1}{10}$ span from the end, causing the maximum strain to pass to the lower flange.

2. $\frac{5}{8}$ or .6 covered causes maximum thrust in the lower flange. The point of contrary flexure in the continuous arch is at $\frac{1}{10}$ in this case also. This is more evident by inspecting the diagrams.

Returning to equation [C] or [$C_1$] where W represents both permanent and passing load on the arch, and $W_1$ the passing load; while $d_x$ is the rise of the arch at $x$ measured from one end, and $h_x$ the corresponding

depth of the rib, where $\frac{1}{z}$ is a factor, it will be noticed that the two second terms are in all respects similar to the well-known equation $\frac{w\,l^2}{8\,d}$ for an ordinary beam; and the strains are, in fact, the same as those of a beam of same span as the arch with top chord varying as the parabola, plus the strain in a beam of half the span and depth equal depth of rib, loaded uniformly with ($w_1$) per running foot, supposing the case of the arch half loaded (VIII.)

Further carrying out this analogy between the straight beam and the arch, which a careful analysis of the elaborate theory of the Coblentz and other hinged bridges clearly shows, the following formulæ and geometric method are given:

CASE I.

## Independent arched beam, or arch hinged at the ends.

Maximum strains in each flange or member:

*Centre.* $x = \frac{l}{2}$.

Each flange:

$$\mathrm{T} = \tfrac{1}{2}\,(w + w_1)\,\frac{l^2}{8\,d} \qquad [1.]$$

*Haunch.* $x = \frac{l}{4}$.

Upper flange:

Open

$$\mathrm{U} = \tfrac{1}{2}\left(w + \frac{w_1}{2}\right)\frac{l^2}{8\,d}\sec\frac{a}{2} \pm \tfrac{1}{2}\,\frac{w_1\,l^2}{64\,q\,h} \qquad [2.]$$

$$\text{“} = \mathrm{A} \pm \mathrm{A}_1.$$

Lower flange $x = \frac{l}{5}$:

$$\mathrm{L} = \tfrac{1}{2}\left(w + \frac{5}{8}\,w_1\right)\frac{l^2}{8\,d}\sec\frac{a}{2} \pm \tfrac{1}{2}\,\frac{w_1\,l^2}{62\,q\,h} \qquad [3.]$$

$$\text{“} = \mathrm{B} \pm \mathrm{B}_1.$$

*End, spring.*

Each flange:

$$\mathrm{T}_1 = \tfrac{1}{2}\,(w + w_1)\,\frac{l^2}{8\,d}\sec\,(a) \qquad [4.]$$

IX. These formulæ give the maximum strains and the points where they occur, and are by themselves quite sufficient for small arches or

preliminary calculations. The factor sec. $\frac{a}{2}$ may ordinarily be omitted, indeed it is an approximation the true value of the first term of equations (2) and (3) may be correctly arrived at by employing equation [A], making $x$ alternately $= \frac{l}{4}$ and $\frac{l}{5}$ and by making $s = \frac{1}{2}\ l$ and $\frac{5}{8}\ l$, and having solved the equation for $M_x = \frac{l}{2}$ and $M_x = \frac{l}{5}$ divide these by the rise of the neutral axis at these points (which may be taken for the vertical ordinate of the line of pressure.) Strain due to temperature will be treated presently.

*Shearing strain:*

$$S = \pm \frac{w_1\ l}{8} \qquad [5.]$$

In a beam whose web is continuous, as rolled or riveted ⊢, $\frac{1}{6}$ the web may be considered as belonging to the flanges; the section of the other $\frac{5}{6}$ must be capable of standing a shearing strain $= \frac{1}{3}$ passing load.

X. From equations $[C_1]$ and [2] it may be noticed that the strains are similar to a pair of rafters; that is, there is a strain due to a beam of span $l$ and depth $d$ + the strain due to a beam or rafter of span $\frac{l}{2}$ and depth $h$ covered with the passing load.

XI. Now taking the case of the Coblentz bridge (Fig. II.) the curve A′ C′ B′ is laid upon A B by the formula

$$\tfrac{1}{2}\ (w + w_1)\ \frac{l^2}{8\ d}\ \sec \alpha .$$

Next curves E F and G H are laid off on A B, by making C F $= \frac{1}{2}\left(w + \frac{w_1}{2}\right)\frac{l^2}{8\ d}$ and C G $= \frac{1}{2}\ (w + \frac{5}{8}\ w_1)\ \frac{l^2}{8\ d}$ and containing the lines F E and G H parallel to A′ C′ B′. If laid off by equation [A] these will be nearly parallel to A B (remembering always to divide $M_x$ by the vertical ordinate of the neutral axis); but this manner is shorter and errs on the side of safety. Next on A C lay off the parabola of which $\frac{1}{2}\cdot\ \frac{w_1\ l^2}{64\ q\ h}$ is the middle ordinate, the difference between this parabola and curve A is the minimum strain in lower member or flange. Laying off the ordinates of this parabola on curve A gives curve A + $A_1$ which is the maximum strain in upper member. A tangent C′ N being drawn,

A′ N C′ is the maximum curve, the ordinates of which give the strain on upper flange.

On the right hand we have a parabolic curve, but differing from the one due to half a load; the vertical ordinates are given in terms of the greatest, which is $\frac{1}{2}\ \frac{w_1\ l^2}{62\ q\ h}$. A similar tangent B T completes the maximum curve and includes the strains due to other positions of the load.

Had the rise been $\frac{1}{10}$ span, these ordinates would have very closely agreed with those given in the German work, while if less than $\frac{1}{10}$, the strains would be a trifle in excess; as it is, the area expressed in square inches agrees within 1 or 2 per cent. throughout. The allowed strain was 4.4 tons compression on the (wrought iron) arch.

*Shearing Strains.* Fig. III. gives the true curve, but as the maximum ordinate is but $\frac{1}{8}$ passing load it generally suffices to calculate this, draw in the curve by eye, erect A $A_1$

$$= \pm \frac{w_1\ l}{\sqrt{1 + 4\ C^2}} .0072,$$

Where $C = \frac{d}{l}$, and draw A′ S, S being .217 $l$ from A.

XII.—These shearing strains are normal to the arch, and if the web is made up of diagonals the shearing strain in any diagonal will be the ordinate of this curve multiplied by the secant of the inclination of the brace with the flange. The shearing strain is both compressive and tensile, therefore the web must be "counterbraced" throughout, if it be composed of bracing.

### Case II.

## The Continuous Arched Beam.

*Maximum Strain in each Flange.*

As in the case of the independent arch. the bending strain due to the passing load, say on half the bridge, was found to be equal to that of a straight beam of half the span $\left(\frac{l}{2}\right)$ and of depth equal the depth of the rib ($h$), supported freely. So it might be expected that in the case before us the bending strain would be equal that of a similar straight girder "built in at one end and on a free support at the other." Applying this in the case of the St. Louis bridge, of Capt. Eads, the author found the curves to be almost identical, and in no point did they vary radically.

XIII.—The geometrical method of expressing such a strain is seen in Fig. IV., as given by Humber's Handy Book of Strains, Art. 28–29, and is the difference between the parabola in Fig. II. and a triangle whose height is equal to or rather, more correctly, a trifle greater than the central ordinate of the parabola.

The curves A′ C′ B′ and E For (A) are the same as in Fig. II. The curves $(A + A_1)$ and $(A - A_1)$ are the ordinates between the parabola and triangle laid off on E F. The point of contrary flexure, or where the strain passes from the upper to the lower flange, is at $(m)$. The dotted lines indicate upper flange, the plain lines the lower flange, and the heavy ones the maximum in each.

XIV.—The maximum strain due $\frac{5}{8}$ load is seen on the right of Fig. IV., but the writer has been able only to furnish formulæ for the middle, end, and centre strains, and to draw the curve by eye between them. This is, however, sufficient, as in practice it is only necessary to calculate the strains by the formulæ that follow, and to make the area constant throughout the middle $\frac{4}{6}$ of the span, even in the largest bridges, while for a tenth or $\frac{1}{12}$ on each end the area may be made to agree with formulæ $U_1$ and $L_1$.

It may be noticed that had the Coblentz bridge been bolted fast at the ends, the strains, with the exception of a short distance at each end, would have been reduced (See Figs. II. and IV.); but if we take strains due to temperature into account in Case II., the great depth of the rib would increase the strains due to this cause more than in Case I.

*Formulæ.*

Maximum strain in each flange.

Centre: $x = \frac{l}{2}$

$$T = \tfrac{1}{2}(w + w_1)\frac{l^2}{8\,d} \qquad (1.)$$

*Haunch:* $x = \frac{l}{3}$

Upper member:

$$U = \tfrac{1}{2}\left(w + \frac{w_1}{2}\right)\frac{l_2}{8\,d}\sec\frac{a}{2} \pm \tfrac{1}{2}\frac{w_1\,l^2}{128\,q\,h} \qquad (2.)$$

$$\text{“} = A \pm A_1.$$

Lower member $x = \frac{l}{4}$

$$L = \tfrac{1}{2}\left(w + \tfrac{5}{8}\, w_1\right)\frac{l^2}{8\, d}\ \sec\ \frac{a}{2} \doteq \tfrac{1}{2}\,\frac{w_1\, l^2}{113\, q\, h} \qquad (3.)$$

$$" = B = B_1.$$

*Spring:*

$$U_1 = \tfrac{1}{2}\left(w + \tfrac{5}{8}\, w_1\right)\frac{l_2}{8\, d}\sec\,(a) \mp \tfrac{1}{2}.\ \frac{w_1\, l^2}{56\, q\, h} \qquad (4.)$$

$$L_1 = \tfrac{1}{2}\left(w + \tfrac{1}{2}\, w_1\right)\frac{l^2}{8\, d}\sec\,(a) \pm \tfrac{1}{2}.\ \frac{w_1\, l^2}{64\, q\, h} \qquad (5.)$$

For values of $q$ see table Sec. V.

The minus sign gives the minimum strain, and this, taking into account strain due temperature, must not be less than zero, otherwise the rib at that point will open, unless it be at the ends where the flanges can, in a metal arch, for the short distance required ($\frac{1}{12}$), be made to resist tension with considerable advantage, as the strain by reducing the depth of the rib (equations 4 or 5) will become tensile or minus at the ends long before at the (2 or 3) quarter points or haunches.

Shearing strain:

*Centre:*

$$S = \pm\,\frac{w_1\, l}{8} \qquad (6.)$$

constant from there each way $\frac{l.}{4}$

From the quarter points to the ends or *spring:* regularly increasing to

$$S_1 \pm \frac{11}{24}\ .\ \frac{w_1\, l}{2} \qquad (7.)$$

which, to include strain due temperature, should be increased $\frac{1}{2}$. This may give too great a strain in some circumstances; but as the entire web does not include much metal even in large bridges, this excess does not amount to much. Section XII. applies equally here.

Fig. V. gives the shearing strains; the dotted lines are the actual strains according to formulæ of Col. Flad, in Capt. Eads' bridge.

### TEMPERATURE.

Strains, both tensile and compressive, are caused by a rise or fall above the ordinary temperature (say of 60°) at which the structure is erected.

In this country the maximum range may be taken at from 120 to 160 degrees, that is, half that amount above and below the mean.

A rise causes increased strain of compression in lower flange, and a corresponding decrease in the upper; likewise a fall produces the reverse.

$(A—A_1)$, see Fig. 2, must never be equal to zero, since the tension due to temperature must be met by compression already in the flange, which can only happen if A (compression) is larger than $A_1$ by a quantity equal to this tension.

If an arch is hinged at the centre as well as at the ends, the strains due to temperature are avoided, and theory applies with greater approach to the actual case. This will be apparent from the fact alone that the line of pressure in this case is fixed in three points.

If a bridge is sufficiently wide to have ample horizontal bracing between the arches to prevent the tendency to overturn, this plan would be most advantageous.

It may be easily shown that the strains due temperature are, in Case I, equal to those in a straight girder of span ($l$) and depth ($h$), uniformly loaded with a weight $W_x$ ; while in Case II., to that of a straight girder *built in at the ends* of depth ($h$) and span ($l$), also uniformly loaded, but with a weight $W_y$. That is, the deflections are the same ; and hence the following formulæ for the increased strain in tons (2,000 lbs.) per square inch, the area taken being that required by the preceding formulæ.

Case I.

Arch hinged:

$$\text{Strain at centre } F = .0004\ E \left(1 + \frac{4\ d^2}{l^2}\right) \cdot \frac{h}{d} \qquad [E.]$$

Case II.

Arch fixed:

$$\text{Strain at centre } F = .000525\ E \frac{h}{d}\left(1 + \frac{4\ d^2}{l^2}\right) \qquad [F.]$$

$$\text{Strain at ends} = .00105\ E \frac{h}{d}\left(1 + \frac{4\ d^2}{l^2}\right) \qquad [G.]$$

or double that at the centre.

Now, in the first case, the ordinates of a parabola, whose middle ordinate is $[E] \times a$, and whose base equals the span, are the extra areas needed.

And those of a parabolic curve, whose middle ordinate is $[F] \times a$, end ordinate is $-[G]\ a$, and zero ordinate is at a point $= .22\ l$, give the extra area in Case II.

*Table.*

Taking a mean value for $\frac{d^2}{l^2}$, the quantity in the parentheses of these formulæ may be taken at 1.05 and substituting values of E, modulus of elasticity in lbs. we have:

| | Case I. | Case II. | |
|---|---|---|---|
| | Centre. | Centre. | Ends. |
| Cast iron..... | $F = 3.28 \frac{h}{d}$ | $F = 4.45 \frac{h}{d}$ | $= 8.9 \frac{h}{d}$ |
| Wrought iron ..... | $= 5.90 \frac{h}{d}$ | $= 8. \frac{h}{d}$ | $= 16 \frac{h}{d}$ |

The accuracy of these formulæ is confirmed by B. Baker's excellent work on "Beams, Columns, and Arches;"* in the third column of the table, however the value of F differs from Baker's. This paper is too small to allow of an argument, but the writer would refer to Humber's Handy Book of Strains, Section 25, "the case of a beam built in and fully loaded," and also to the elaborate calculations in the case of Capt. Eads' bridge at St. Louis, where may be noticed the strain at ends, due to temperature equal twice that at the centre.

These formulæ when applied to the Coblentz, Victoria, St. Mauritz, and to other bridges, the elaborate calculations of which we possess, give correct results; for steel, however, judging from the St. Louis bridge, the only example of Case II. in steel, which we have to test by, the formulæ (F) and (G) give a too low result by about one-half. As steel must of necessity play a much more important part in bridge-building in the future than in the past, the writer regrets not being able to account for this disparity, nor to furnish a simple formula to apply to the case.

*Economic Depth.*

It may be well to call attention to the fact that F depends directly on the depth of rib ($h$) and indirectly on the rise ($d$), and therefore the greater the rise and the smaller the depth the smaller the strain; $\frac{1}{10}$ span has been a very usual rise, but as low as $\frac{1}{5}$ has been used, and lately it has been demonstrated that $\frac{1}{7}$ span is a fair average for economy.

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* P. 269. F is there the long ton, and for only 30° instead of 60°, as above.

The minimum depth ($h$) may be arrived at approximately by the following formulæ: $f = \frac{\text{F}}{\text{allowed press.}}$, say $4\frac{1}{2}$ to 5 tons for wrought iron, 5 for cast iron, and 8 and 12 for steel.

Then,

Case I.:

$$h = \frac{8\ w_1\ d}{62\ q} \cdot \frac{1}{((1 - \frac{3}{2}f)\ w + (\frac{5}{8} - \frac{3}{2}f)\ w_1}.$$

Case II.:

$$h = \frac{8\ w_1\ d}{113\ q \sec \frac{a}{2} \left((1 - f)\ w + (\frac{5}{8} - f)\ w_1\right)}$$

which may be taken usually at

$$h = \frac{8\ w_1\ d}{57\ [(1 - f)\ w + (\frac{5}{8} - f)\ w_1]}.$$

*Deflection.*

When totally loaded an arched beam will deflect so as to cause the neutral axis to pass considerably below the line of pressure. The effect of this is not to add to the total pressure at all, but to increase the amount in the upper flanges with a corresponding decrease in the lower. To counteract this, a very flat wedge or wedges are introduced behind the bearings at the abutments, and the arch is sprung up as much above its true curve as it may be expected to deflect. This has been successfully tried in a number of foreign bridges. Baker recommends making the arch to fit a longer span, so that when compressed by the load it will settle to the required rise, and gives the following formula for the excess in inches of the new span:

$$= \frac{\text{T}\ l \left(\frac{w + w_1}{w_1} + 1\right)}{800\ \frac{(w + w_1)}{w_1}\ a}$$

$a$ = sectional area of the flanges.

This may be put

$$= \frac{w\ l^3}{6400\ a\ d},$$

for wrought iron, $1\frac{5}{4}$ this amount for cast iron, and $\frac{3}{4}$ for steel—depending upon their elasticity.

The advantages of cast iron over wrought, and also those of steel, the greatest allowable pressure per square inch and practical details, are points of interest which should be discussed. Before leaving this subject I would at least point out that Sections IV. and X. suggest the best probable method of stiffening an arch, either by making the arch of section equal to formula [1], Case I. or II., and putting two beams and a tie as in Fig. 7, capable of standing the bending strain, or in the case of the bow-string doing the same thing, only reversed, the diagonals being ties, and the inclined a strut; the roadway to be hung from the arch by simple suspenders.

*Values of quantities used in this paper.*

$M_x$ = moment at point whose hor. ordinate is $x$.

H = T = horizontal thrust at centre, due total load.

$l$ = span, in feet.

$d$ = rise measured to neutral axis, also in feet.

$h$ = depth of rib, in feet.

$c = \frac{d}{l}$.

$w$ = permanent load in tons per foot.

$w'$ = passing " " " "

$\frac{a}{2}$ = area in square inches calculated from T.

$f = \frac{\text{temp. pressure per inch.}}{\text{allowed pressure per inch.}}$

ton = 2000 lbs.

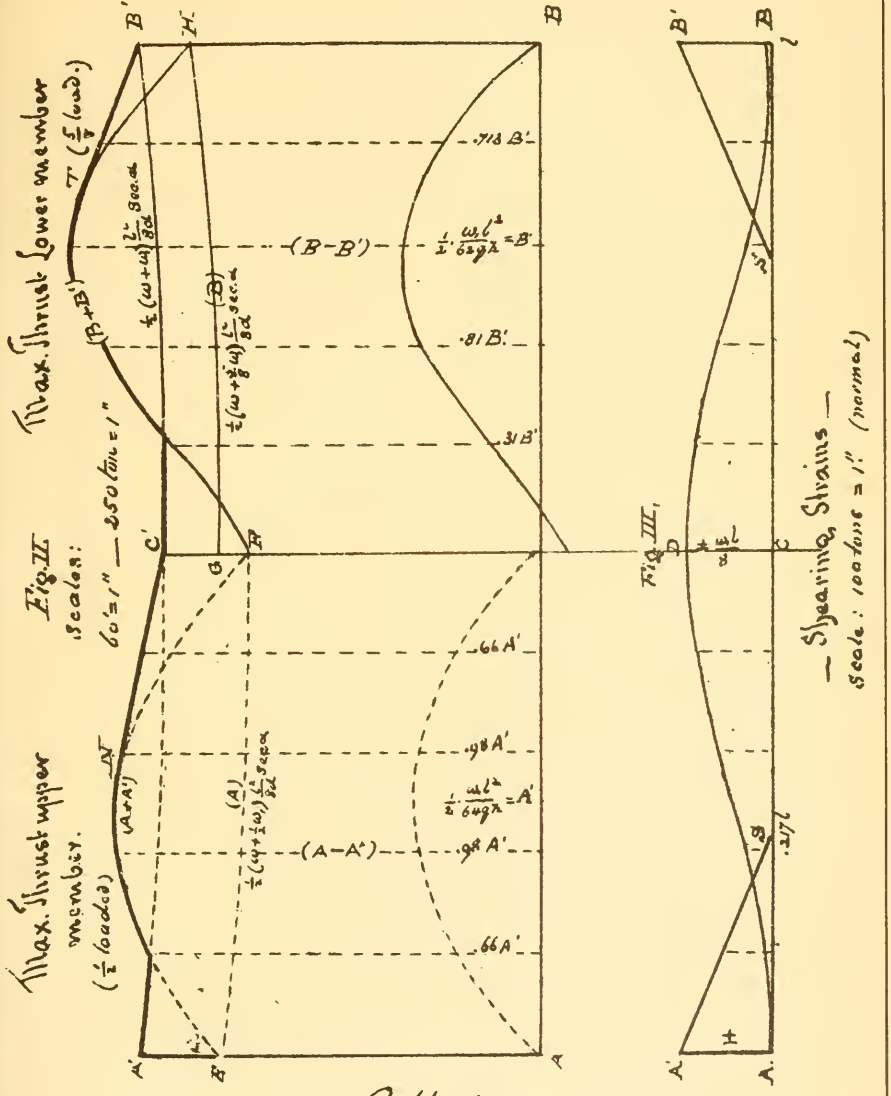
$\alpha$ = angle between horizontal and the curve of neutral axis at any point.

$a$ = value at $\alpha$ at the spring.

T, U, L, etc. = thrust in tons for the points to which they refer.

# Case I.

## The Independent Arched Beam.




## Coblentz

### Data.

| | | | |
|---|---|---|---|
| Span | $l = 312.4'$ | Perm.t load | $\omega = 1\frac{1}{2}$ tons |
| Rise | $d = 23.4'$ | Passing " | $\omega_1 = 1$ " |
| Depth | $h = 9.5'$ | Allowed press. per □" = 4.4 tons in compression. | |
| Angle $\alpha$ | $= 19°27'$ | | |

A'NC should be dotted.

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XXXII.

# Case II.

## The Continuous Arched Beam.

Data same as case I.

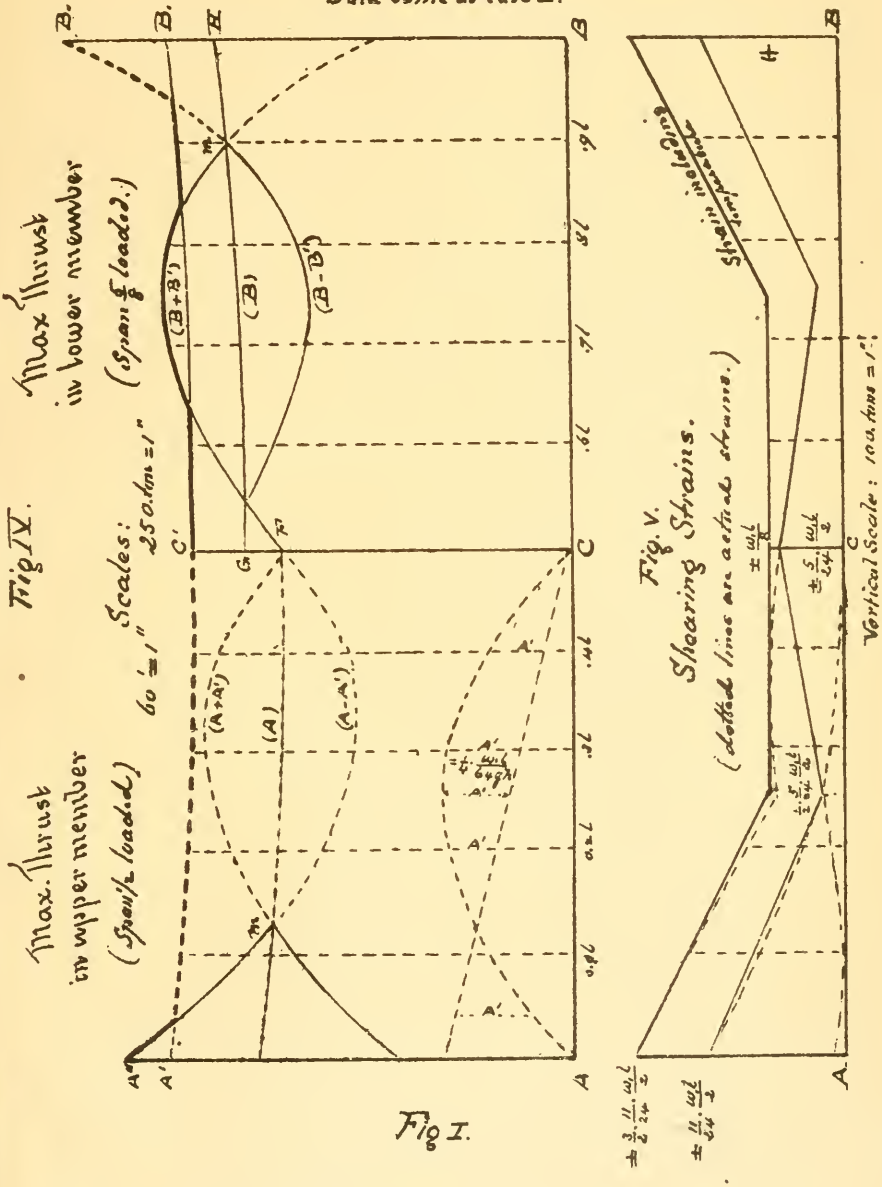
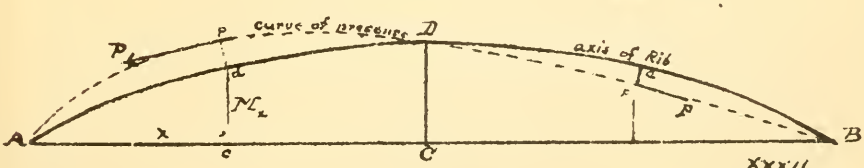



Fig I.

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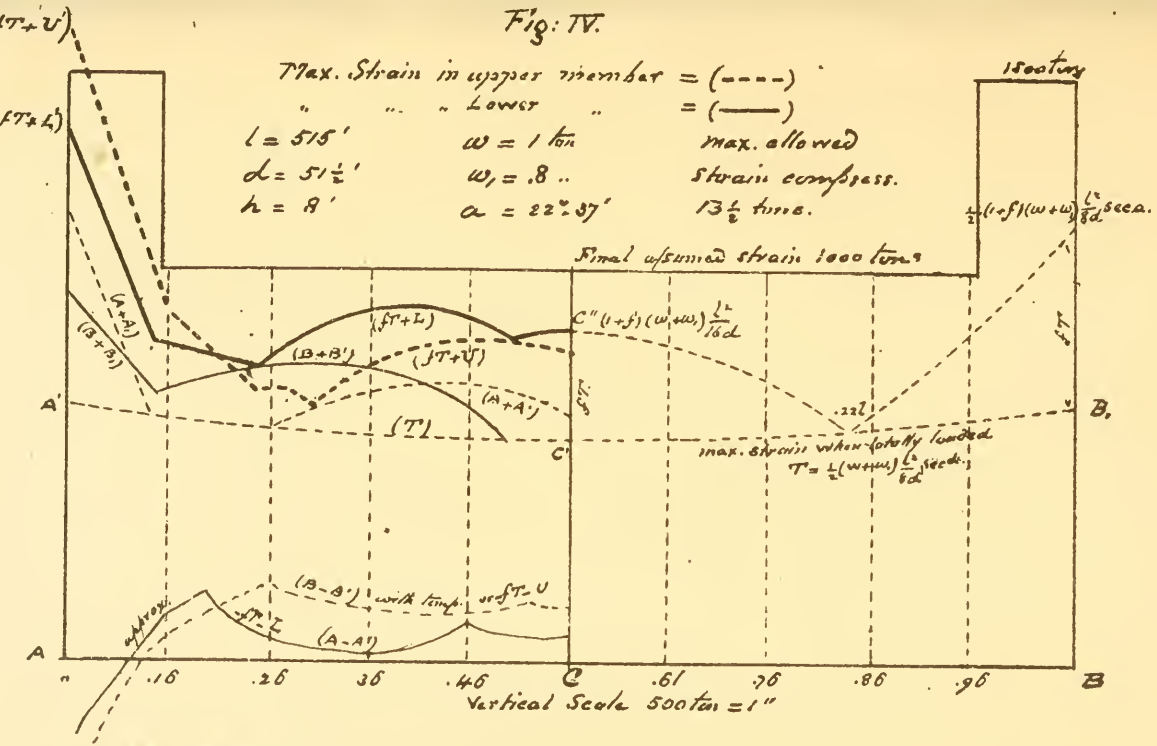
Case IV.
Actual strains St Louis Bridge. Capt. Eads.

Fig: IV.




Curve on right is temperature curve for neutral axis. Rest of Upper Member is a parallel line below axis of Lower member as parallel line above this curve.

Fig VII

Fig. VIII.

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